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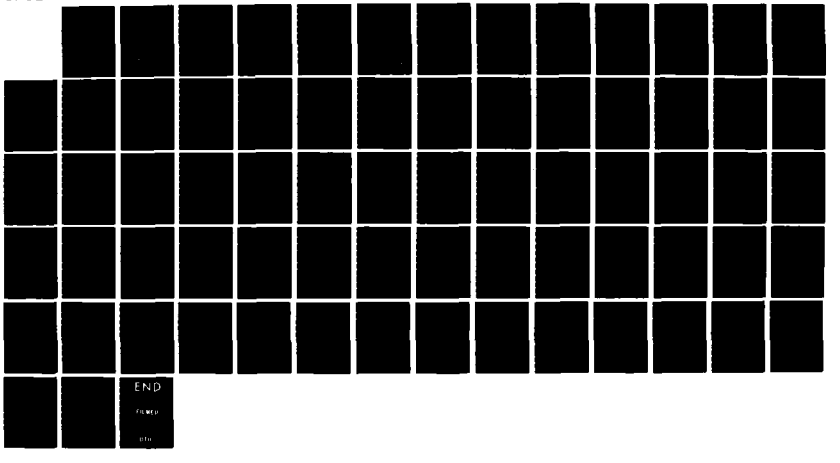

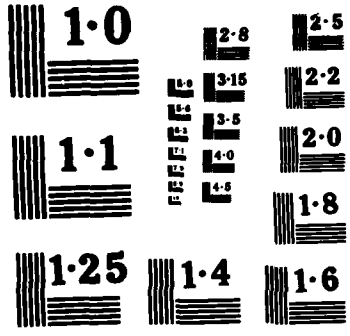

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MICROCOPY RESOLUTION TEST CHART

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DOT/FAA/CT-85/1

Practical Real-Time Quality Control of Antimisting Kerosene

Robert Hoover
Augusto Ferrara

May 1985
Final Report

US Department of Transportation
Federal Aviation Administration
Technical Center
Atlantic City Airport, N.J. 08405

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16. Abstract

Antimisting kerosene was developed to provide fire protection during impact survivable crashes. When the technique of blending AMK from a slurry was developed, a need arose to insure the quality of the individual blends. This report describes a die swell test procedure developed for real-time quality control of inline blended AMK. The procedure provides readouts on the concentration of the antimisting additive in the fuel and it indicates in real-time any non-homogenity of the blended AMK. Additional tests are described which show the behavior of AMK is time dependent. Originator

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- Mr. Joseph Wilson of the FAA Technical Center for laboratory support.

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LIST OF SYMBOLS

A_w - Area of the tube wall, cm^2

D - Inside tube diameter, mm

$\overline{D}$ - Average inside tube diameter calculated from viscosity calibrations using a fluid with a known viscosity, mm

D_j - Jet diameter, mm

L - Tube length, cm (or inches)

n - Slope of the shear stress versus coreccted shear rate curve, Pa·sec

n' - Slope of the shear stress versus uncorrected shear rate curve, Pa·sec

P - Pressure drop across tube or along a length of tubing, Pa (or psi)

P_c - Pressure drop corrected for end effects, Pa (or psi)

P_e - End effects correction, Pa (or psi)

ΔP - Uncorrected pressure drop across tube, Pa (or psi)

Q - Flow rate, mℓ/min.

R - Tube radius, mm

V - Fluid velocity, cm/sec.

x - The effective concentration from the Die Swell versus Concentration Curve, % on a weight/weight basis

y - The average effective concentration from the Divisions versus Concentration Curves, % on a weight/weight basis

z - The effective concentration from the Delta Divisions versus Concentration Curve, % on a weight/weight basis

$\dot{\gamma}_R$ - Corrected shear rate at tube wall, sec^{-1}

η - Intrinsic viscosity, Pa·sec

μ_a - Apparent viscosity, Pa·sec

ν_{11} - ν_{22} - Normal stress, Pa

ρ - Density, gm/cm^3

τ_{12} - Shear stress, Pa

EXECUTIVE SUMMARY

Antimisting kerosene (AMK) was developed to provide fire protection in impact-survivable crashes. Tests conducted at Southwest Research Institute (SwRI) showed that Imperial Chemical Industries' FM-9 polymer and other additives providing fire protection develop significant normal stresses. The die swell test, which provides an estimate of the normal stresses, was selected from a number of tests because it provides the best measure of quality when combined with shear stress measurements.

SwRI, under contract to the Technical Center, fabricated a unit to investigate the die swell phenomena. The Technical Center modified the unit to eliminate the need to correct for kinetic energy changes and end effects. These modifications were based on earlier work, which showed how the behavior of AMK changes with time.

With die swell data taken over a fixed range of shear rates at discrete time intervals, Center engineers were able to estimate the concentration of AMK during the inline blending process. The sensitivity of the predictions for a given slurry batch was determined to be within ..02 percent.

Moreover, the predicted AMK concentration correlated well with its performance in large-scale test systems. Substandard polymer lots displayed reduced flammability resistance as predicted by die swell measurements of the concentrations for the blended AMK.

Sensitivity testing also demonstrated the inability of other techniques such as the filtration ratio, orifice flow cup, and clarity to give precise indications of the blended AMK concentration and, consequently, fire protection.

INTRODUCTION

In the recent past, post-crash fires have claimed a number of lives following impact-survivable aircraft accidents. A large fire ball often results when fuel is spilled from ruptured tanks and ignited by either hot engine components, random hot spots, or sparks which occur during the crash. Antimisting kerosene (AMK) was developed to prevent spilled fuel from breaking into easily ignitable droplets.

Antimisting kerosene made with FM-9 (developed by Imperial Chemical Industries (ICI)), thickens while it is sheared. The early quality control devices (i.e., the filter ratio and orifice cup tests) were designed to measure this gelling phenomena. It was soon recognized that this sudden shear thickening of AMK could not fully explain the fire protection provided. Samples of Jet A were mixed with mineral oil to obtain the same apparent shear viscosity as AMK. These samples burned like neat Jet A (reference 1). An additive, supplied by the ARCO Chemical Company, provided fire protection equivalent to that provided by FM-9 on both the Flammability Comparison Test Apparatus and the Wing Spillage Facility at the Federal Aviation Administration (FAA) Technical Center. This additive shear thins unlike FM-9 which shear thickens. Jet thrust tests conducted at Southwest Research Institute and the Jet Propulsion Laboratory showed that above a certain shear rate, antimisting kerosene, made with FM-9 polymer, generates large normal stresses (references 1 and 2) as does the ARCO additive. Torsional balance and hole error experiments confirmed the observation that both additives generate significant normal stresses of the same order of magnitude.

A program was undertaken at Southwest Research Institute to develop a practical test for estimating the magnitude of these normal stresses. The method developed utilized a commercially available optical system for determining the diameter of the stream ejected from a capillary tube and a pressure transducer placed upstream of the tube. An estimate of the shear stress is obtained by correcting the pressure measurement for kinetic energy changes and end effects. This information is combined with the jet diameter to obtain the magnitude of the normal stresses (references 3 and 4). Experiments conducted on the apparatus showed the normal stresses are an order of magnitude greater than the shear stresses for both the ARCO additive and FM-9. Also, the normal stresses for both additives appeared to fall on the same line (reference 4). This combination of similar normal stresses and similar fire protection strongly implies that the die swell measurement will prove an effective indicator of fuel quality.

The die swell apparatus was delivered to the Technical Center for further testing.

DIE SWELL

Die swell is a phenomena associated with visoelastic materials. For a Newtonian fluid, a stream of fluid contracts as it exits a long die, such as a capillary tube. For non-Newtonian fluids, the normal stresses tend to pull the fluid back towards the exit of the die and the stream appears to swell. Studies have been conducted which relate the increase in diameter to the magnitude of the normal stresses. Changes in the amount of polymer in solution will affect the magnitude of the normal stresses and, hence, the amount of die swell observed. The theory and equations are given in detail in reference 3.

Experiments, where the pressure drop along the length of capillary tube is measured, are complicated by changes in the kinetic energy of the fluid and end effects. The end effects become even more significant when the behavior of the fluid is non-Newtonian. The classic technique for eliminating the kinetic energy effect is to calculate the change in pressure required to increase the velocity of the fluid to the average velocity through the tube and subtract it from the total pressure drop. To correct for the end effects, the pressure drop across a number of tubes of different lengths is measured for a given shear rate. This is repeated for a number of different shear rates and the corrected pressures are plotted on semi-log scale. A curve is fit to the data for that shear rate and the y intercept is determined. The magnitude of this intercept is the estimated pressure drop which occurs at the ends of the capillary tube. Both steps introduce small errors which are normally negligible. The wall shear stress for a given shear rate is then calculated from the total pressure drop for that shear rate less the kinetic energy and end effect corrections.

In a log/log plot of the shear stress against shear rate, the slope of the curve relates to the behavior of the fluid. Newtonian fluids have a slope of 1. Fluids which shear thicken have a slope greater than 1, those that thin with increasing shear rate have a slope less than 1.

Antimisting Kerosene (AMK) made with FM-9 polymer behaves like a Newtonian fluid below a certain critical shear rate. When the shear rate of the fluid exceeds this critical shear rate, AMK abruptly thickens, then behaves as a shear thinning fluid. Once the shear stress is removed, AMK returns to its Newtonian behavior (relaxes) in approximately 2 seconds.

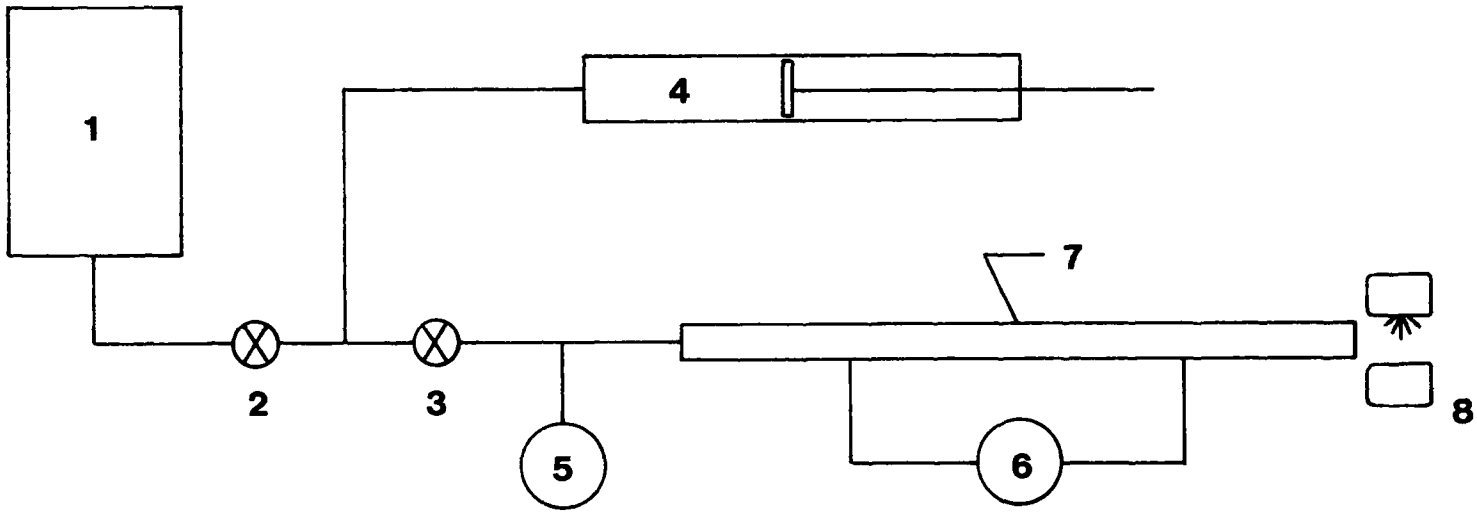
TEST APPARATUS.

The die swell apparatus used for these experiments was constructed at Southwest Research Institute. The apparatus uses a Zeneth™ metering pump to regulate the flow rate, hence, the shear rate of the fluid. The pump circulates hydraulic fluid to both sides of a hydraulic ram which actuates a hydraulic piston (item 4 in figure 1). By varying the speed of the pump, the velocity of the piston is changed. A shuttle valve controls the direction of flow of the hydraulic fluid, allowing the test fluid to be drawn into the cylinder through valve 2 or discharged from the cylinder through valve 3 (figure 1). The valves are manually operated ball valves, which were selected to keep the shear rate to a minimum. All tubing upstream of the capillary tube was selected to keep the shear rate of the test sample well below the critical shear rate of AMK made with FM-9. To keep degradation to a minimum, the test sample is loaded into the piston at low pump speeds (typically below a setting of 10).

The unit was provided with a capillary tube whose internal diameter was 2.95 mm and whose length was 191 times the radius (L/R = 191). The pressure drop across the tube was measured using a pressure transducer at position 5 (figure 1). The pressure measured at position 5 has to be corrected for kinetic energy changes and end effects.

Located at the discharge of the capillary tube is an optical sensor which is capable of measuring the diameter of the stream as it emerges from the capillary tube. The sensor is manufactured by C. W. Brabender, Hackensack, New Jersey. The unit gives a real-time display of the measured diameter and it generates an analog voltage which is proportional to the measured diameter. The output from the

DIE SWELL



LEGEND:

1) RESERVOIR
2) VALVE FOR LOADING FUEL
3) VALVE FOR CAPILLARY TUBE
4) HYDRAULIC PUMP, VARIABLE SPEED
5) PRESSURE GAUGE, TOTAL PRESSURE DROP
6) PRESSURE GAUGE, PRESSURE DROP FROM L/R OF 50 TO L/R OF 150
7) CAPILLARY TUBE, L/R 200
8) OPTICAL SENSOR

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FIGURE 1. SCHEMATIC OF THE DIE SWELL METER

optical sensor and the pressure transducer is recorded on a strip chart recorder for further analysis. A sample trace is shown in figure 2.

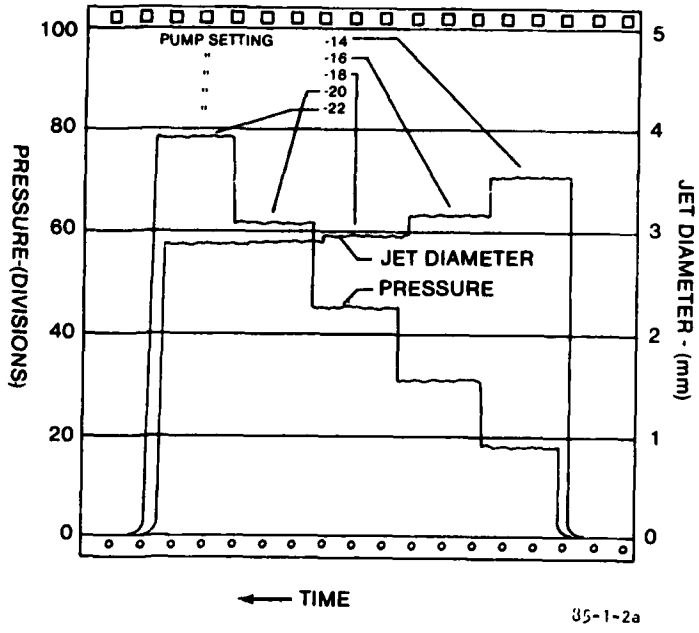
The unit was modified at the Technical Center to allow for a different technique of obtaining the shear stress and slope of the shear stress versus shear rate curves. This technique uses two pressure taps along the capillary tube. Each tap was assembled to allow for a smooth transition along the walls and a clean transition to the sample port (see figure 3). The upstream pressure tap is located at an L/R of 50 and the downstream pressure tap is located at an L/R of 150. This is shown schematically as item 6 in figure 1. If one assumes that the hole errors associated with non-Newtonian fluids at each location are the same, then this technique provides a better measure of the shear stress along a length of tube (L/R = 100) without the need to correct for changes in kinetic energy or end effects. For fluids which are not time dependent, such as AMK made with the ARCO additive, this assumption is a good one. The behavior of AMK made with FM-9 is time dependent and an effort was made to compensate for this time dependency. The length of tubing upstream of the first pressure tap was made long enough for the viscoelastic behavior to develop and the length between the two taps was kept as short as practical to minimize the changes in hole error due to changes in behavior. Vents were incorporated at the transducer to allow air to be bled from the system prior to testing.

TEST PROCEDURES.

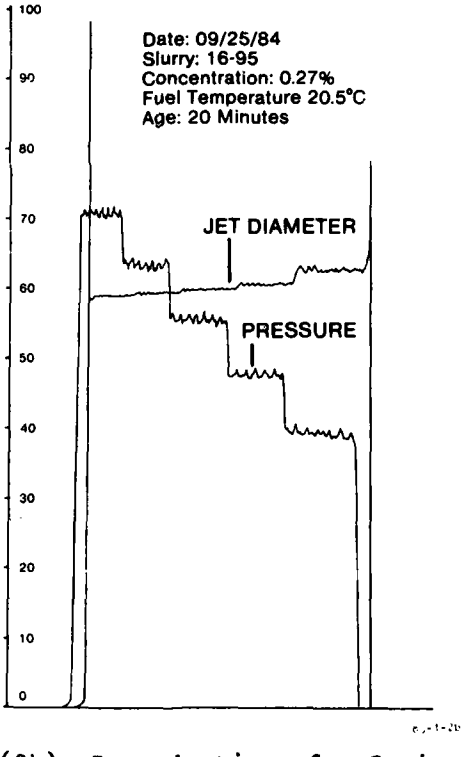
For proper operation of the die swell meter, the assembled units, optics, and stripchart must be calibrated. Calibration is performed by placing a standard size rod in the optical sensor and adjusting the digital readout and the stripchart reading to the known size of the calibration rod. After the test fluid is poured into the storage reservoirs, valves 2 and 3 (refer to figure 1) and the transducer vents are opened to bleed the lines leading to the capillary tube, the capillary tube, and the differential tranducer.

The test fluid is loaded into the pump cylinder by placing the pump lever in reverse with valve 2 open, valve 3 closed, and the pump speed set low; i.e., 10, to avoid polymer degradation in the AMK. The time required to completely load the pump cylinder at a pump setting of 10 is approximately 3 minutes. After the pump cylinder is loaded, the desired pump speed is set to obtain the corresponding shear rate from table 1. With valve 2 closed and valve 3 open, the pump lever is placed forward and the fluid flows through the capillary tube at the set shear rate. Measurements of the pressure drop in the capillary and the jet diameter of the fluid leaving the capillary tube are recorded on the stripchart. After flow has been established and the die swell and pressure drop readings are stable, a new shear rate may be set by changing the pump speed to the next desired setting. About five different shear rates can be tested during each run of the die swell meter. At the end of each run, the pump lever is placed in neutral to avoid damaging the pump. If a new fluid is to be tested, the pump must be drained and cleaned to avoid contamination. The pump is then loaded as before. If the same fluid is to be tested, the storage reservoir is refilled, and the pump is reloaded as before. The die swell meters' checklist and operating procedures are found in appendix A.

Pump Setting	Shear Rate (sec. $^{-1}$)
14	4409
16	5311
18	6279
20	7348
22	8450



(2a) Strip chart Legend



(2b) Reproduction of a Strip Chart Recording

FIGURE 2. STRIP CHART LEGEND AND A REPRODUCTION OF A STRIP CHART RECORDING

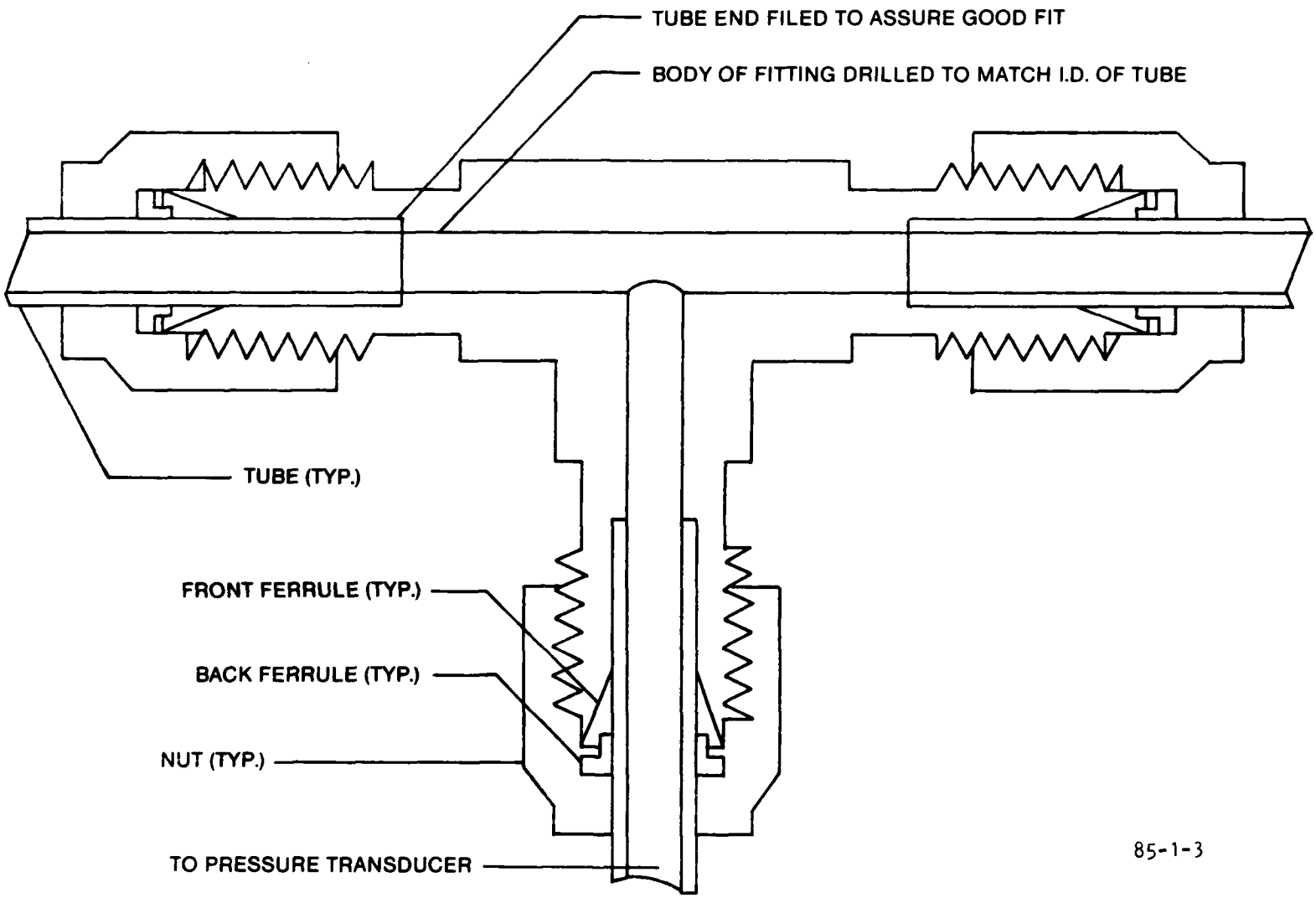


FIGURE 3. CROSS SECTION OF T-TUBE FITTING USED IN DIE SWELL AND CAPILLARY TUBE EXPERIMENTS

TABLE 1. APPARENT SHEAR RATE AND FLOW RATE VERSUS PUMP SPEED

PUMP SETTING	Q mℓ/min	$\frac{8V}{D}$ s^{-1}
5	60	401
6	120	802
7	190	1269
8	250	1670
9	320	2138
10	385	2572
11	455	3039
12	525	3507
13	590	3941
14	660	4409
15	725	4843
16	795	5311
17	865	5778
18	940	6279
19	1020	6814
20	1100	7348
21	1180	7882
22	1265	8450
23	1355	9051
24	1455	9719
25	1550	10354
26	1645	10989
27	1750	11690
28	1850	12358
29	1960	13093
30	2060	13761
31	2170	14496
32	2280	15230
33	2390	15965
34	2500	16700
35	2610	17435

For the majority of the tests conducted at the Technical Center, pump settings of 14, 16, 18, 20, and 22 were used giving corresponding shear rates of 4409, 5311, 6279, 7348, and 8450 sec^{-1}. At pump settings less than 14, the stream of high concentration AMK (0.30 percent and above) would drop below the level necessary for the die swell optics to accurately measure the jet diameter. At pump speeds greater than 22, the pressure drop in the capillary tube for high concentration AMK would exceed the limitations on the 10 pounds per square inch, differential (psid) transducer.

During most of the die swell meter testing, one gallon samples with a known concentration of FM-9 were blended using a mini-blender. The mini-blender pumps a measured amount of Jet A through a tube where a known amount of slurry is fed inline. The Jet A and FM-9 mixture flows through a mixing tube into a storage container. The average blend time is 2-1/2 minutes. The operating procedures and diagram for the mini-blender are in appendix B. Die swell tests were also performed on AMK blended in a 10 gal/min inline blender and a 50 gal/min inline

blender using FM-9. These blenders operate in the same manner as the mini-blender, but on a much larger scale. Information on these blenders is in appendix C. Samples taken from the 50 gal/min (190ℓ/min.) blender were drawn out of a barrel 75 meters away from the blender, so the average age of the sample of AMK when drawn was 90 seconds. This time was taken into consideration when calculating the age of the fuel.

Data recorded by the stripchart on the die swell meter was reduced on a Hewlett-Packard™ 9830 computer. The data reduction program plots the shear stress and the calculated normal stress versus the corrected shear rate. The program can correct for kinetic energy effects for data obtained using the original capillary, and the program is easily adapted to reduce data for different tube lengths and measurements from other transducers. Running procedures and the program listing are in appendix D.

DIE SWELL TEST RESULTS.

SHORT-TIME HISTORY. The initial tests on the die swell meter were conducted in order to determine how the rheological properties of AMK, made with FM-9, develop with time. A sample of 0.30 percent FM-9 AMK was drawn from the 10 gal/min inline blender and tested on the die swell meter 6 minutes after blending. The same sample was tested every 3 to 4 minutes afterward until the drawn sample was exhausted 31 minutes after blending. Calculations from the stripchart readings showed viscoelastic development with time by an increase in the calculated normal stresses and an increase in the apparent shear viscosity. The sample equilibrated rheologically 20 minutes after blending; i.e., there were no significant changes in the die swell parameters beyond 20 minutes after blending. Data obtained from this test were from the original capillary tube supplied with the die swell meter. Calculated normal stresses for this blend of AMK were an order of magnitude greater than the shear stresses of the AMK as seen in figure 4.

NEWTONIAN FLUID RUNS. To establish the validity of the die swell meter and the governing equations for the calculation of the normal stresses, a test using a Newtonian fluid was conducted. Initially, neat Jet A was used; but, when the data were reduced, normal stresses on the same order of magnitude as AMK were calculated and the Jet A appeared to be shear thickening. This problem was investigated, and it was found that the Reynolds number in the tube was above 2200 sec^{-1} for the shear rates used. At this Reynolds number, turbulence in the capillary tube caused a "breakup" of the fluid stream thus giving an extraordinarily large jet diameter and a higher pressure drop in the capillary tube.

To obtain an acceptable Newtonian fluid run, mineral oil was diluted with Jet A to make a test fluid which has approximately the same viscosity as the apparent viscosity of the shear thickened AMK. The Jet A mineral oil mixture was run through the die swell meter and results from the test showed that the jet diameter was between 0.04 and 0.26 mm greater than the theoretical diameter. This was attributed to surface tension wetting of the end of the capillary tube. Because of this, the jet diameter of the fluid was essentially constant over shear rates tested, and the calculated normal stresses were on an order of magnitude lower than the calculated normal stresses observed in 0.30 percent FM-9 AMK. The slope of the τ_{12} versus $\dot{\gamma}_R$ curve was 0.95, near the theoretical value of 1 for a Newtonian fluid. Results from this test demonstrated that the die swell meter was able to detect the differences between a Newtonian fluid and a viscoelastic fluid with the

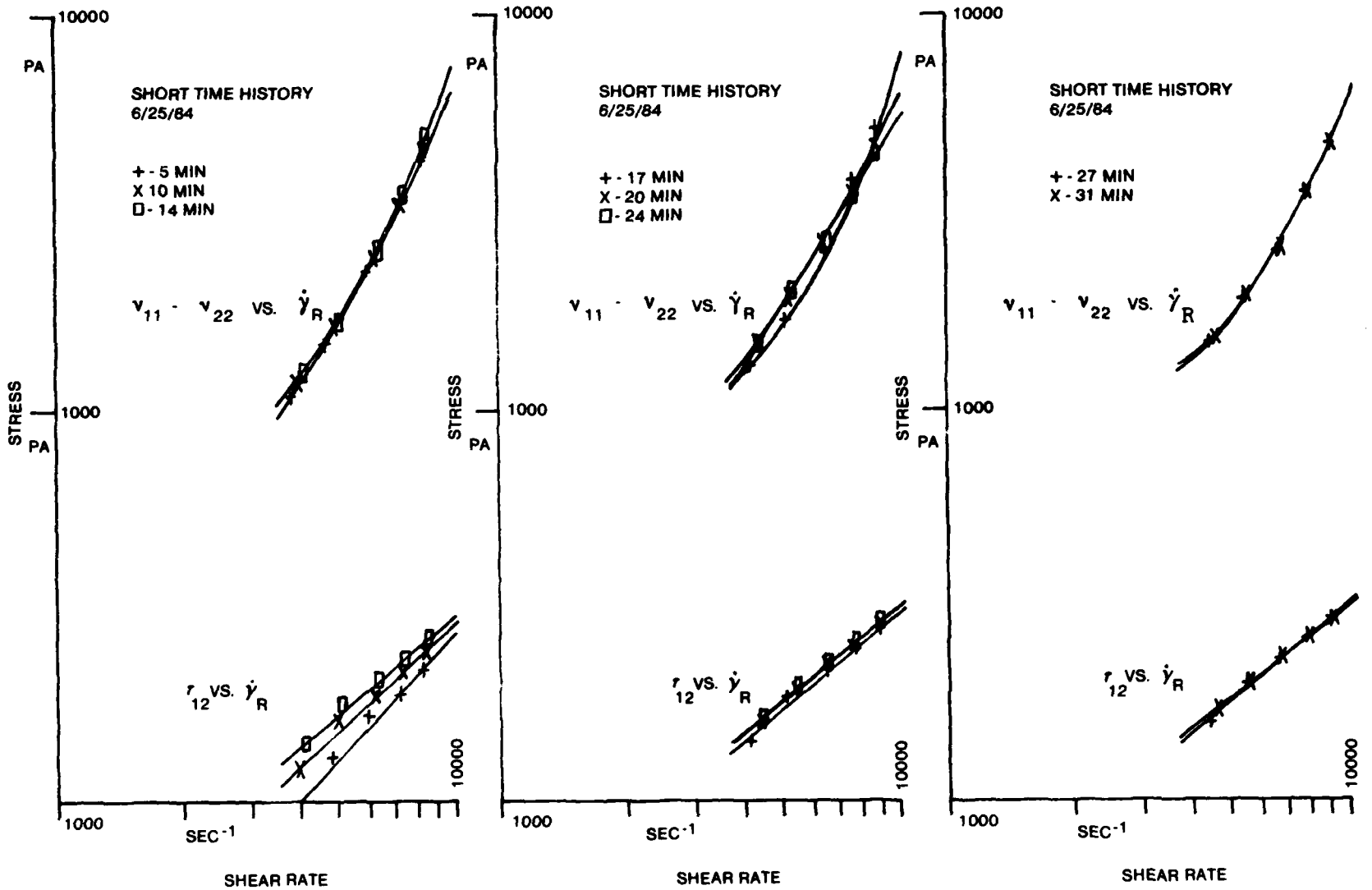


FIGURE 4. REDUCED DATA FROM THE SHORT TIME HISTORY. SHEAR STRESS (τ_{12}) AND NORMAL STRESS ($\nu_{11} - \nu_{22}$) VERSUS SHEAR RATE

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same apparent viscosity. Also, results from the die swell meter can be affected by turbulence in the fluid, which will exaggerate the viscoelasticity of a fluid with a low apparent viscosity.

COMPARISON OF TWO SHEAR STRESS MEASUREMENTS. Tests were run, using both the original setup and the modified capillary tube developed at the Technical Center, in order to compare the two different techniques. A sample of equilibrated AMK was tested on both tubes at the same shear rates, and the rheological properties of the AMK were compared. No significant differences were found between the techniques when computing the apparent viscosity or when determining the slope of the shear stress versus shear rate curve (i.e., the level of shear thining). Significant differences were recorded in the jet diameter of the AMK, leaving the two tubes at the higher shear rates. It was noticed that the new tube was flattened and differences in jet diameter could occur if the end section of the new capillary tube was rotated. This problem was corrected. Pressure readings taken across the whole length of the new capillary tube and across a section of it showed that the apparent shear stress, the amount of shear thinning, and the calculated normal stresses were within 2 percent of each other. The apparent shear stress across the whole length of the capillary tube was slightly higher than the shear stress across a length of the tube. Most of the errors occurred because the end effects for the capillary tube which was supplied with the unit were not calculated for this test prior to calculating shear stress, thus making the AMK appear more viscous.

MINI-BLENDER RUNS. When blending AMK it is essential to know the quality of the fuel during or just after the blend. To make the die swell meter an acceptable quality control device, a baseline needed to be generated. This baseline consists of a number of blends of FM-9 AMK whose concentration was precisely controlled and tested according to a set format. Since most future blends of AMK will be made with a concentration of 0.30 percent FM-9, the planned statistical base would consist of two 0.20 percent, five 0.25 percent, five 0.30 percent, five 0.35 percent, and two 0.40 percent FM-9 one gallon mini-blends. These blends were tested on the die swell meter using the tube with the FAA modification, 5, 9, and 20 minutes after blending at the standard shear rates; 4409, 5311, 6279, 7348, 8450 sec^{-1}. All the mini-blends were made with the same slurry (lot No. 16-95) and base fuel, and they were blended at about the same temperature (16° C to 20° C). To accompany the die swell results, runs of existing quality control tests (filter ratio, orifice cup, and nephelometer) were performed. For these blends, the filter ratio and orifice cup tests were run 30 minutes after blending, while four nephelometer readings were taken between 15 and 30 minutes after blending.

During the Jet A runs, turbulence can be seen as an increase in jet diameter and as an apparent shear thickening. For the mini-blend runs, turbulence was noted for blends with a concentration lower than 0.30 percent. The amount depended upon shear rate and the time after blending, with the 20-minute old fuel showing less turbulence than 5-minute old fuel. Samples, whose concentration was above 0.30 percent, did not show any sign of turbulent behavior. Some samples at 0.30 percent concentration exhibited this turbulent behavior while others did not. If there was turbulence, it was only for the five-minute data and the higher shear rates (7348 and 8450 sec^{-1}). This anomaly appears to be related to small changes in the FM-9 dissolution rate. The cause of this shift in the dissolution rate has not been determined.

During the first two 0.30 percent FM-9 test runs, small particles of translucent gel, "fish eggs," were found in the AMK. The die swell data for these two runs were low when compared to later 0.30 percent FM-9 runs. Since the filter ratio was also low, these two runs were not used in the baseline calculations and were replaced by three other 0.30 percent FM-9 runs. It was decided that these "fish eggs" were contaminants from inside the mini blender that resulted from improper cleaning prior to storage.

While preparing the data from the 20 mini-blends, it was noted that the same results could be obtained if either the raw data or the reduced data were used. Since it takes approximately 20 minutes to reduce the data on the Hewlett Packard 9830, it was decided to use the raw data. Eliminating this step makes estimates of the equivalent concentration available within 30 minutes of blending.

A family of curves was prepared for each time period (i.e., for 5, 9, and 20 minutes after blending) by plotting the average values for each shear rate against concentration.

As the concentration increases, there is a corresponding increase in the pressure drop, which is recorded in divisions (100 divisions equals full scale). This is the same as an increase in the apparent shear viscosity. In figure 5, the average number in divisions is plotted against concentration for a shear rate of 4409 sec^{-1}. This curve is based on the 20-minute data. Similar curves exist for all five shear rates. To obtain the equivalent concentration of an unknown sample, the number of divisions at each shear rate is obtained; the concentration for each shear rate is read from the corresponding curve; and the average is computed.

In a similar manner, jet diameter increases with concentration at a given shear rate. The curves for jet diameter versus concentration become flatter as the shear rate increases. To reduce errors related to reading such flat curves and errors induced by turbulence at higher shear rates, only the curve for a shear rate of 4409 sec^{-1} is used. In figure 6, the jet diameter at 4409 sec^{-1} and 20 minutes is plotted against concentration. The effective concentration of an unknown sample can be read from the curve given the jet diameter for that time period and shear rate.

At a given time, the slope of the apparent viscosity versus shear rate curve decreases with concentration. (The further the slope is from one, the more viscoelastic the fluid.) The slope is approximated by subtracting the pressure drop (in divisions) at a shear rate of 4409 sec^{-1} from the pressure drop at 8450 sec^{-1}. The delta division curve in figure 7 shows this approximate slope as a function of concentration for 20 minutes. In the case of an unknown sample, the number of divisions at 8450 sec^{-1} less the number at 4409 sec^{-1} is calculated, then the effective concentration is read from the stripchart.

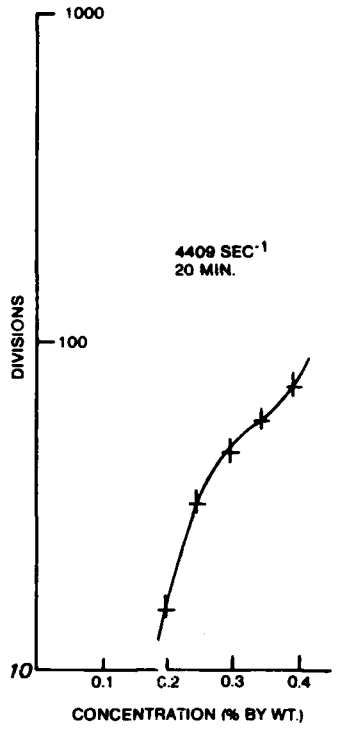


FIGURE 5. THE DIVISIONS VERSUS CONCENTRATION CURVE FOR 20-MINUTE OLD FUEL AT A SHEAR RATE OF 4409 sec^{-1}

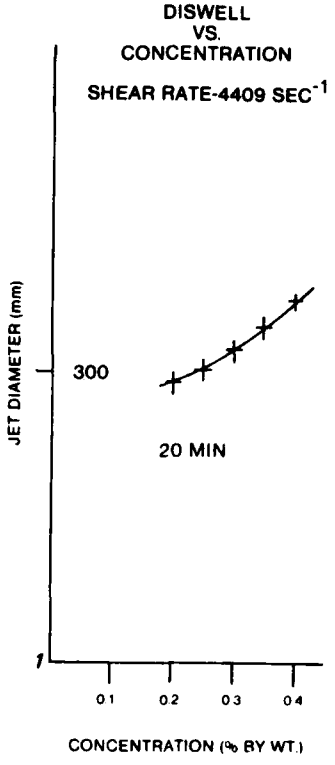


FIGURE 6. THE DIE SWELL VERSUS CONCENTRATION CURVE FOR 20-MINUTE OLD FUEL

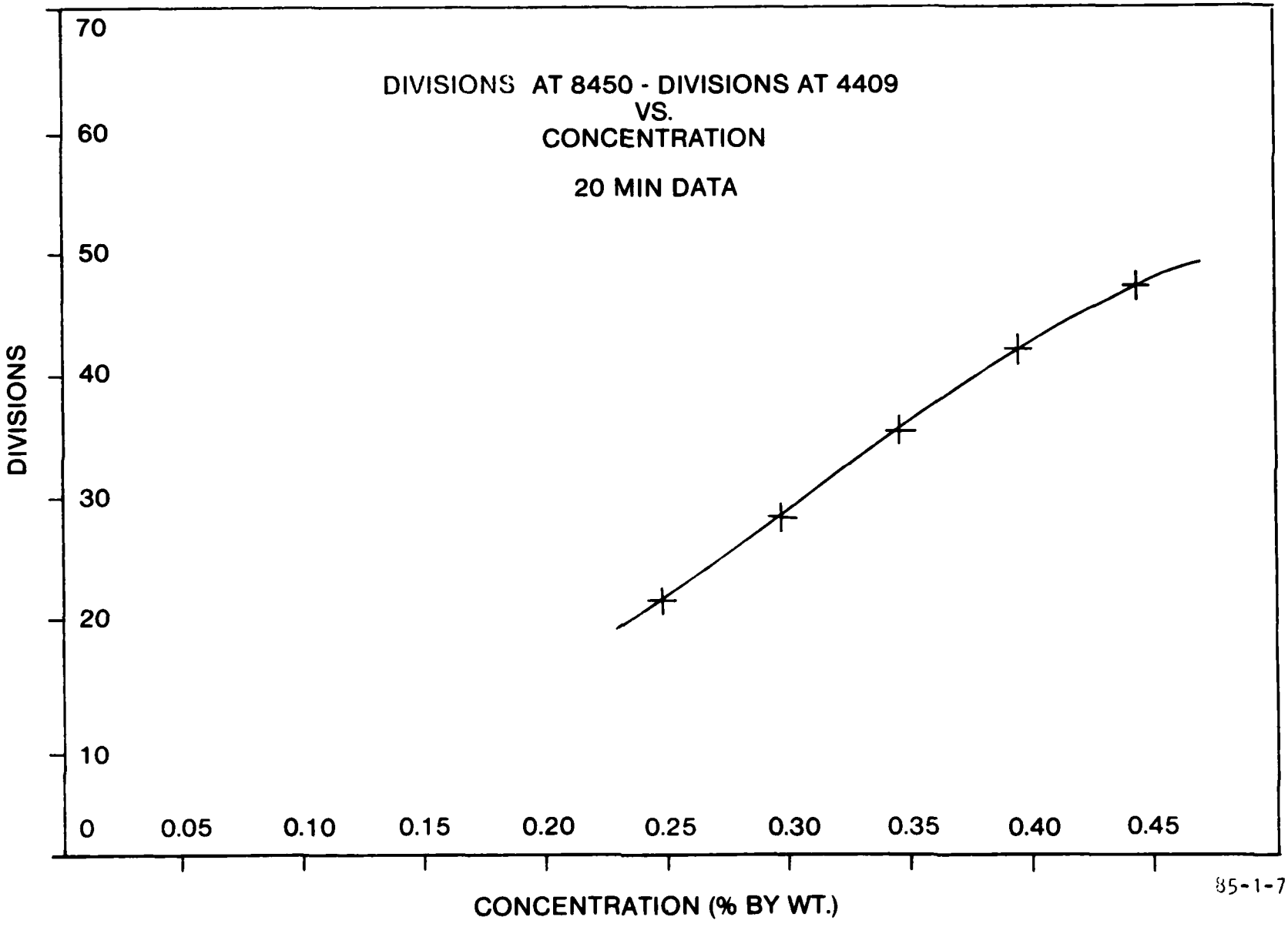


FIGURE 7. THE DELTA DIVISIONS VERSUS CONCENTRATION CURVE FOR 20-MINUTE OLD FUEL

The effective concentrations read from the above are then averaged to obtain the overall effective concentration at that point in time. The complete set of curves generated from the 20 mini-blends is included in appendix E.

While calculating the average values, the standard deviations were also calculated from the test data. Standard deviations for the 5-minute data were three times higher than the standard deviations for the 20-minute data. The explanation for this is that at 5 minutes, the rheological development of AMK is much more rapid than at 20 minutes, where the AMK is near rheological equilibration; thus a small change in procedures could cause a large difference in results. For well equilibrated AMK, the 20-minute data curves were used to determine the equivalent concentration.

To check the accuracy of the quality control curves, two more mini-blends were made and tested on the die swell meter using the same slurry and base fuel (mini-blends numbers 20 and 21). The effective concentration was determined by using the following formula:

$$\text{EFFECTIVE CONCENTRATION} = \frac{x + y + z}{3}$$

where:

x = The effective concentration from the Die Swell versus Concentration Curve

y = The average effective concentration from the Divisions versus Concentration Curves

z = The effective concentration from the Delta Divisions versus Concentration Curve

The effective concentration for each of those two blends was within 0.01 percent FM-9 concentration of the actual concentration. Effective concentrations were determined for all of the previous mini blends and all were within 0.02 percent FM-9 concentration of the actual concentration. A listing of the effective concentration of the mini blends tested and their actual concentration is in table 2.

SLURRY AND BASE FUEL EFFECTS. An examination of different slurries and base fuels was conducted.

A sample of 16-98 slurry was blended into the FAA's Jet A and tested on the die swell meter. This blend had a lower effective concentration than expected, so two more blends were made (table 2 mini-blends numbers 22, 23, and 24). All three blends had lower than normal pressure drops in the capillary tube and smaller than expected jet diameter. These samples also had lower filter ratios (31 for a 0.30 percent concentration as compared with 45) and higher cup volumes (2.9 m versus 2.4 m for a 0.30 percent concentration) indicating that the 16-98 slurry is not as rheologically sound as the 16-95 slurry.

Two lots of Jet A were brought to the Technical Center to compare the behavior of AMK blended with Jet A from different regions of the country. Lot-II came from the depot at Dreyden and Lot-III came from Mojave, California. Antimisting kerosene blended from Lot-II was similar to AMK blended from the FAA's Jet A (table 2 blend number 28). The dissolution rate was lower for Lot-III than for the FAA's

TABLE 2. EFFECTIVE CONCENTRATION* FOR A NUMBER OF MINI-BLENDS

BLEND NUMBER	BASE FUEL	SLURRY	PREDICTED CONCENTRATION BASED ON SHEAR STRESS *	PREDICTED CONCENTRATION BASED ON NORMAL STRESS *	PREDICTED CONCENTRATION BASED ON DELTA DIV. *	EFFECTIVE CONCENTRATION *	ACTUAL CONCENTRATION *
1**	Lot-I	16-95	0.28	0.27	0.28	0.28	0.30
2**	Lot-I	16-95	0.29	0.27	0.30	0.29	0.30
3	Lot-I	16-95	0.31	0.30	0.30	0.30	0.30
4	Lot-I	16-95	0.30	0.30	0.30	0.30	0.30
5	Lot-I	16-95	0.30	0.30	0.30	0.30	0.30
6	Lot-I	16-95	0.35	0.35	0.36	0.35	0.35
7	Lot-I	16-95	0.35	0.35	0.35	0.35	0.35
8	Lot-I	16-95	0.34	0.35	0.35	0.35	0.35
9	Lot-I	16-95	0.36	0.36	0.35	0.36	0.35
10	Lot-I	16-95	0.35	0.35	0.34	0.35	0.35
11	Lot-I	16-95	0.40	0.41	0.40	0.40	0.40
12	Lot-I	16-95	0.40	0.39	0.40	0.40	0.40
13	Lot-I	16-95	0.25	0.25	0.25	0.25	0.25
14	Lot-I	16-95	0.25	0.26	0.25	0.25	0.25
15	Lot-I	16-95	0.25	0.25	0.25	0.25	0.25
16	Lot-I	16-95	0.24	0.24	0.24	0.24	0.25
17	Lot-I	16-95	0.25	0.25	0.25	0.25	0.25
18	Lot-I	16-95	0.20	0.20	0.20	0.20	0.20
19	Lot-I	16-95	0.20	0.20	0.20	0.20	0.20
20	Lot-I	16-95	0.29	0.28	0.28	0.28	0.28
21	Lot-I	16-95	0.28	0.29	0.28	0.28	0.27
22	Lot-I	16-98	0.26	0.28	0.26	0.27	0.30
23	Lot-I	16-98	0.26	0.27	0.27	0.27	0.30
24	Lot-I	16-98	0.28	0.29	0.29	0.29	0.32
25	Lot-I	16-95	0.28	0.29	0.29	0.29	0.30
26	Lot-I	16-95	0.29	0.31	0.29	0.30	0.30
27	Lot-I	16-98	0.29	0.30	0.33	0.31	0.35
28	Lot-II	16-95	0.30	0.32	0.30	0.31	0.31

Lot-I fuel was drawn from FAA reserves
Lot-II fuel was drawn from NASA Dreyden reserves

*(Concentration is in % on a weight/weight basis.)
**(Contained Multiple Fish Eggs)

Jet A. This is evident by observing that the effective concentration of the 10/15 blend in table 3 increases slightly with time.

A number of different slurries and base fuels were used to make blends of AMK for testing at the FAA Wing Spillage Facility. Samples of these blends were tested at the standard shear rates, 5, 9, and 20 minutes after blending. The effective concentration was determined from the quality control charts and compared to the actual concentration determined from the gum bath solids tests. This comparison is summarized in table 3.

The pass/fail velocities from the Wing Spillage tests (reference 6) were plotted versus effective concentration from the die swell (for 20-minute old fuel) and are shown in figure 8. A linear relationship appears to occur between the two parameters plotted. This pass/fail line then is a measure of how well a blend of AMK measured on the die swell meter will perform on a full-scale fire test. From this curve, the failure velocity of a blend of AMK on the wing spillage test can be predicted within 10 knots.

RELATED OBSERVATIONS. The lab tests discussed below are described in appendix F.

Thirty-minute filter ratio data from the baseline mini-blends were plotted versus the percent concentration of FM-9 in AMK (figure 9). A linear relationship occurs between filter ratio and the percent FM-9 concentration; however, there is a large amount of scatter. The uncertainty in the filter ratio data results in relatively large errors if attempting to determine the concentrations from a single filter ratio test. For example, a sample whose concentrations is 0.30 percent, may appear to have a concentration somewhere between 0.25 and 0.35 percent. Changes in base fuel or slurry lot affect the slope of the filter ratio versus concentration curve. This means a new curve must be defined for each new combination of slurry and base fuel if the filter ratio is to be used to measure concentration.

The other two quality control tests, run on the 30-minute old, mini-blended AMK, were ineffective in predicting the actual concentration of FM-9. Average orifice cup readings of 2.4 mℓ were measured for all baseline mini-blends containing 0.25 percent, 0.30 percent, and 0.35 percent FM-9. The cup test, at 30 minutes, appears to be insensitive to FM-9 concentration in the critical 0.25 percent to 0.35 percent FM-9 range (figure 9 and table 4). The cup test was affected by changes in base fuel and slurry lot. The cup value would shift (e.g., from 2.4 to 2.9) but the general shape of the curve would remain the same.

The nephelometer readings all decreased with time from 15 to 30 minutes after blending, but all points were scattered and no differentation could be seen between different concentrations of FM-9.

A test conducted at the Jet Propulsion Lab indicated that fuel blended with 16-98 slurry would equilibrate, then decay with time. A series of tests was conducted on two samples. One blend contained 16-95 slurry and the other 16-98 slurry. The effective concentrations were measured for up to 2 weeks (see blend date 10-4 and 10-5 in table 3). No significant changes were noted during this period.

TABLE 3. EFFECTIVE CONCENTRATION FOR A NUMBER OF LARGE-SCALE BLENDS

DATE OF BLEND	SLURRY	BASE FUEL[1]	SAMPLE LOCATION	AGE	Predicted Concentration (%) SHEAR STRESS	NORMAL STRESS	DELTA DIV.	EFFECTIVE CONC.	ACTUAL CONC. (%)	PASS VEL. (KTS)	FAIL VEL. (KTS)
8-28[2]	16-95	lot-IV	Wing	34 days	0.31	0.30	---	0.31	0.30	---	---
8-29[3]	16-95	lot-I	Wing	33 days	0.11	0.12	0.16	0.13	0.30	---[4]	120
10-4	16-98	lot-I	Hose	5 min.	0.27	0.28	0.30	0.28	0.30	160[4]	170
10-4	16-98	lot-I	Hose	9 min.	0.28	0.30	0.30	0.29	0.30	"	"
10-4	16-98	lot-I	Hose	20 min.	0.26	0.28	0.31	0.28	0.30	"	"
10-4	16-98	lot-I	Hose	18 hrs.	0.28	0.30	0.29	0.29	0.30	"	"
10-4	16-98	lot-I	Tank	18 hrs.	0.27	0.30	0.30	0.29	0.31	"	"
10-4	16-98	lot-I	Tank	5 days	0.27	0.29	0.32	0.29	0.31	"	"
10-4	16-98	lot-I	Tank	6 days	0.27	0.30	0.32	0.30	0.31	"	"
10-4	16-98	lot-I	Tank	7 days	0.27	0.29	0.33	0.30	0.31	"	"
10-4	16-98	lot-I	Tank	11 days	0.26	0.29	0.32	0.29	0.31	"	"
10-4	16-98	lot-I	Tank	12 days	0.26	0.28	0.32	0.29	0.31	"	"
10-4	16-98	lot-I	Tank	13 days	0.26	0.28	0.33	0.29	0.31	"	"
10-5	16-95	lot-I	Hose	5 min.	0.31	0.33	0.33	0.32	0.34	170[4]	---
10-5	16-95	lot-I	Hose	9 min.	0.34	0.34	0.34	0.34	0.34	"	---
10-5	16-95	lot-I	Hose	20 min.	0.35	0.34	0.33	0.34	0.34	"	---
10-5	16-95	lot-I	Tank	4 days	0.40	0.37	---	0.39	0.37	"	---
10-5	16-95	lot-I	Tank	5 days	0.38	0.37	---	0.38	0.37	"	---
10-5	16-95	lot-I	Tank	6 days	0.40	0.36	---	0.38	0.37	"	---
10-5	16-95	lot-I	Tank	10 days	0.39	0.36	---	0.38	0.37	"	---
10-5	16-95	lot-I	Tank	11 days	0.38	0.36	---	0.37	0.37	"	---
10-5	16-95	lot-I	Tank	12 days	0.39	0.37	---	0.38	0.37	"	---
10-9	16-98	lot-I	Hose	5 min.	0.25	0.27	0.25	0.26	0.30	140[4]	150
10-9	16-98	lot-I	Hose	9 min.	0.25	0.25	0.25	0.25	0.30	"	"
10-9	16-98	lot-I	Hose	20 min.	0.23	0.26	0.27	0.25	0.30	"	"
10-9	16-98	lot-I	Hose	18 hrs.	0.25	0.28	0.26	0.26	0.30	140[5]	150
10-10	Exp.[6]	lot-I	Hose	5 min.	0.30	0.31	0.31	0.31	0.31	140[4]	150
10-10	Exp.[6]	lot-I	Hose	9 min.	0.31	0.32	0.31	0.31	0.31	"	"
10-10	Exp.[6]	lot-I	Hose	20 min.	0.23	0.27	0.28	0.26	0.31	"	"
10-10[7]	Exp.[6]	lot-I	Hose	16 hrs.	0.26	0.26	0.29	0.27	0.31	"	"
10-10[7]	Exp.[6]	lot-I	Tank	16 hrs.	0.21	0.24	0.28	0.24	0.30	130	140
10-11	16-95	lot-I	Hose	5 min.	0.25	0.23	0.26	0.25	0.28	---	---
10-11	16-95	lot-I	Hose	9 min.	0.28	0.28	0.27	0.28	0.28	---	---
10-11	16-95	lot-I	Hose[8]	20 min.	0.28	0.29	0.28	0.28	0.28	---[4]	---
10-11[9]	16-95	lot-I	Tank[8]	28 min.	0.30	0.31	0.30	0.30	0.30	170[4]	---
10-12[9]	16-95	lot-I	Tank	45 min.	0.15	0.15	0.15	0.15	0.20	---[4]	120
10-15	16-95	lot-III	Hose	5 min.	0.24	0.24	0.24	0.24	0.30	150[4]	160
10-15	16-95	lot-III	Hose	9 min.	0.27	0.29	0.28	0.28	0.30	"	"
10-15	16-95	lot-III	Hose	20 min.	0.27	0.31	0.28	0.29	0.30	"	"
10-15	16-95	lot-III	Tank	1 day	0.30	0.31	0.28	0.30	0.30	"	"
10-15	16-95	lot-III	Tank	2 days	0.33	0.32	0.27	0.31	0.30	"	"

Footnotes on next page

FOOTNOTES FOR TABLE 3

1) lot-I, Fuel from the FAA Technical Center's reserve
   lot-II, Fuel from NASA Dryden
   lot-III, Fuel from Mojave, California
   lot-IV, Fuel from Miami, Florida

2) Sample from trial blend conducted at Miami, Florida.

3) Sample of fuel drawn from the wing of the CV880 after a flight from Miami to Atlantic City.

4) Wing Spillage tests conducted 30 minutes after the conclusion of blending.

5) Wing Spillage test conducted approximately 18 hours after the conclusion of blending with the temperature of the AMK raised to 90°F.

6) An experimental slurry designed to equilibrate faster than other slurries.

7) Additional fuel was blended into the tank of the Wing Spillage Facility after the Wing Spillage test the previous day. The additional fuel lowered the actual concentration.

8) The rate of slurry injection was increased during the blend. The hose sample drawn early in the blend was not representative of the bulk of the fuel.

9) This is the dilution of the 10-11 blend discussed in text. Concentrations quoted are rough estimates.

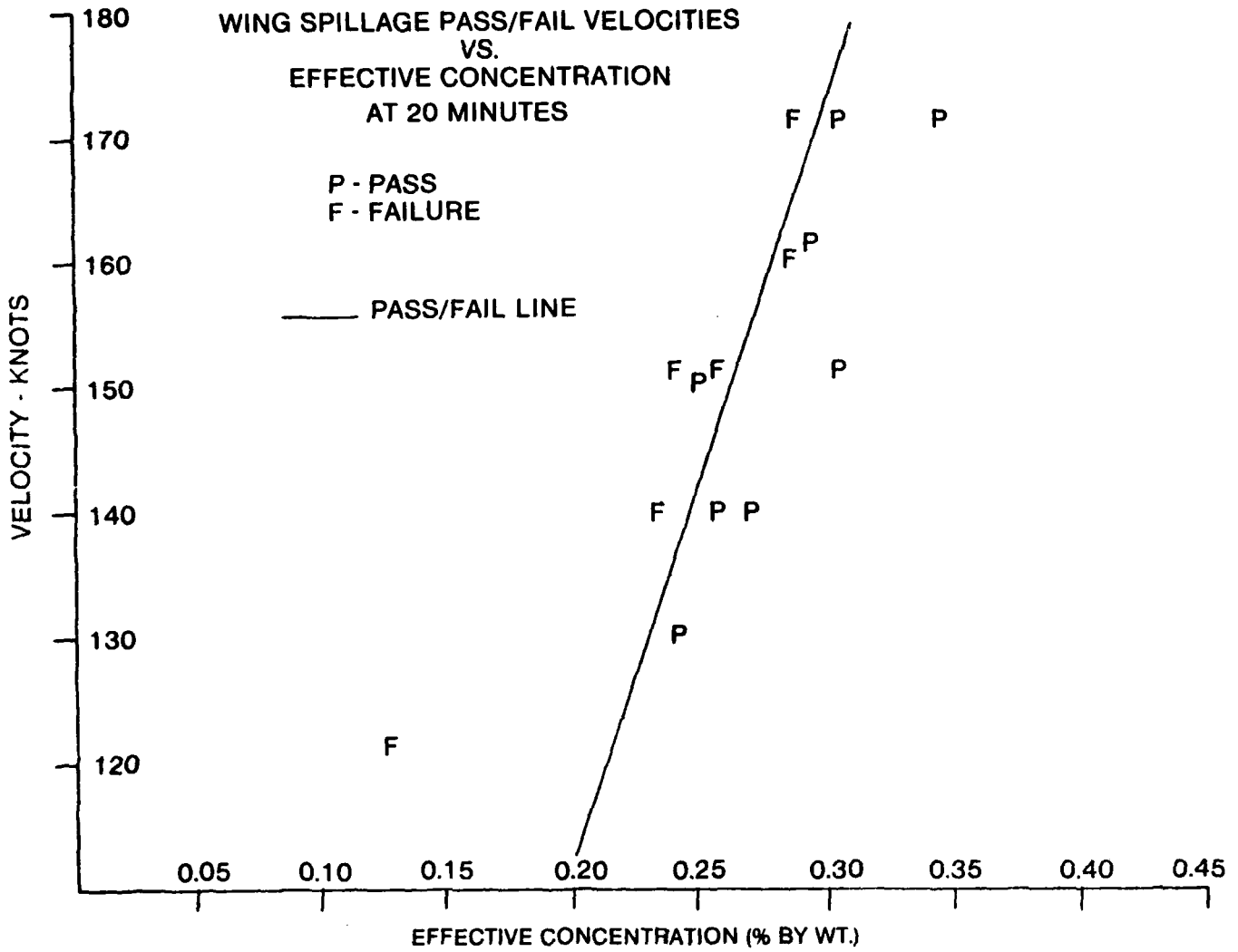
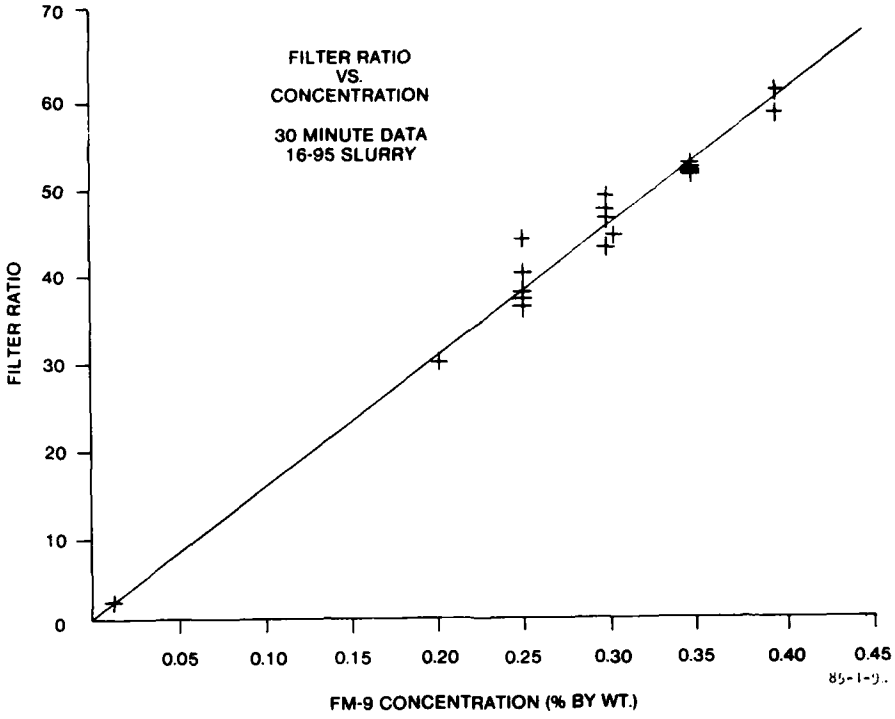
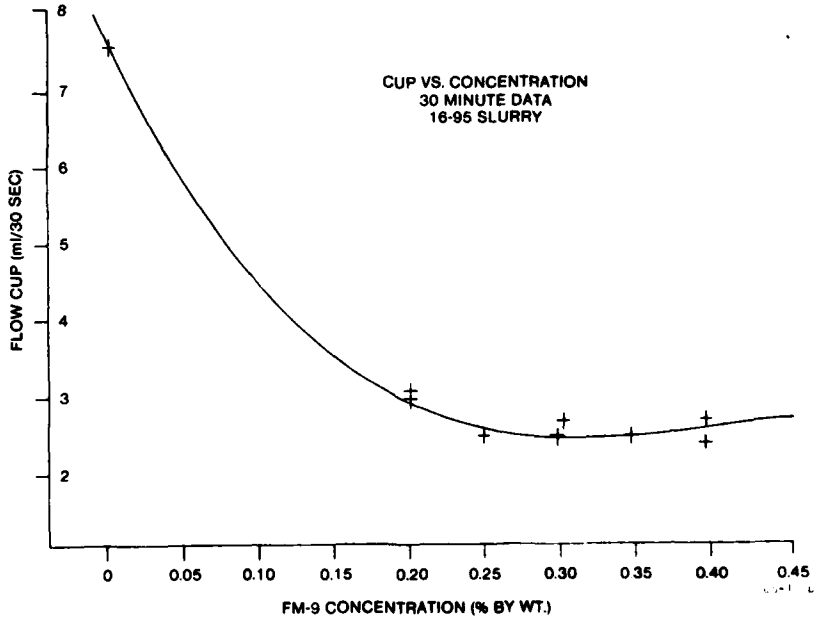


FIGURE 8. WING SPILLAGE TEST RESULTS VERSUS EFFECTIVE CONCENTRATION PASS/FAIL BOUNDARY INDICATED



(9a) Filter ratio versus concentration. Filter rates tests conducted on 30 minute old fuel.



(9b) Orifice cup versus concentration. Cup tests conducted 30 minutes after blending.

FIGURE 9. FILTER RATIO AND ORIFICE CUP READING VERSUS CONCENTRATION FOR 30-MINUTE OLD ANTIMISTING KEROSENE

TABLE 4. DATA COMPARING FILTER RATIOS AND CUP MEASUREMENTS AGAINST CONCENTRATION, 16-95 SLURRY, FAA JET A

Actual Concentration %	Filter Ratio	Cup (mℓ/30sec)
0.20	29.4	2.9
0.20	29.5	3.0
0.25	39.6	2.4
0.25	43.6	2.4
0.25	37.4	2.4
0.25	35.7	2.4
0.25	36.6	2.4
0.30	53.0	2.4
0.30	43.5	2.4
0.30	45.9	2.4
0.30	48.5	2.4
0.30	46.9	2.4
0.30	42.5	2.2
0.30	48.4	2.4
0.35	51.3	2.4
0.35	50.9	2.4
0.35	51.1	2.4
0.35	52.1	2.4
0.35	51.7	2.4
0.40	60.5	2.6
0.40	57.9	2.3

DILUTED AMK RUN. A sample of equilibrated AMK with a concentration 0.30 percent FM-9 was diluted with Jet A to make the actual concentration equal to 0.20 percent FM-9. This diluted AMK was tested 45 minutes after dilution on the die swell meter, filter ratio, orifice cup, and nephelometer. Results from the die swell meter showed an effective concentration much less than 0.20 percent FM-9, closer to Jet A. Orifice cup data was 6.4 mℓ and the filter ratio was 92.0, with 1/8-inch clear gel forming on the filter. The nephelometer reading was normal with a reading of 8 Nephelometry Units (NTU). This AMK took greater than 5 seconds to relax, once disturbed, as compared to less than 2 seconds for virgin AMK. One hour after dilution, this sample failed the Wing Spillage test at 120 knots, which implies the effective concentration was less than 0.20 percent.

CAPILLARY TUBE EXPERIMENTS

These experiments were initiated as a part of the AMK quality control effort. It had been verbally reported that AMK's behavior appears to change with time if it is maintained above the critical shear rate (reference 5). These reports implied that the rate of change was dependent upon concentration, but there was no way of quantifying these apparent changes. The experiments described below were initiated to investigate this phenomena further.

TEST APPARATUS.

A schematic of the test apparatus is shown in figure 10. The apparatus is essentially a long capillary tube with pressure taps located at selected locations. At each junction special care was taken to insure the wall of the tube was smooth

and no changes in inside diameter occurred. The length of the tubing between items 5 and 6 and items 7 and 8 were carefully matched, and they both have a length to diameter ratio of 100 (L/D = 100). The total L/D for the tube was 1000, and it was constructed of tubing with an O.D. of 0.125 inch and an I.D. of 0.075 inch. The test sample was pumped using a peristaltic pump which allowed for a range of shear rates (8V/D) from just below 800 sec^{-1} to 8000 sec^{-1}. All the tubing prior to point 4 in figure 10 was designed to keep the shear rates well below the critical shear rate and the Reynolds Numbers below 100. A small accumulator, item 3 in figure 10, was needed to dampen out the pulses associated with the peristaltic pump. The transducer was a 0-20 inch Hg wet/wet unit manufactured by Sensotec™. Valves 10 and 11 are manual ball valves which allow for switching the transducer between the upstream and downstream segments with an L/D of 100. The output voltage was read manually from a digital multimeter and recorded on a run sheet.

In designing these experiments, it was assumed that the normal stresses would not change substantially over an L/D of 100 and the hole errors would cancel.

TEST PROCEDURES.

Place a six-liter test sample in the reservoir and secure the inlet to the pump. Start the pump and set it to the slowest speed possible. Purge the air from the system by carefully manipulating the nylon tubing and by bleeding the system through valves 12 and 13 in figure 10. Adjust the pump speed to provide an 8V/D of approximately 800 and monitor the output of the pressure transducer until it stabilizes, indicating that the flow rate had stabilized. Record the pressure between locations 5 and 6 in figure 10 then switch valves 10 and 11 to obtain the pressure between locations 7 and 8. The switching of valves 10 and 11 must be done simultaneously, otherwise the pressure between points 5 and 8 in figure 10 is applied across the transducer and it may be damaged. The actual flow rate is determined by collecting a sample over a given period of time. The shear rate is then estimated using the formula 8V/D, where V is the average velocity and D is the inside tube diameter.

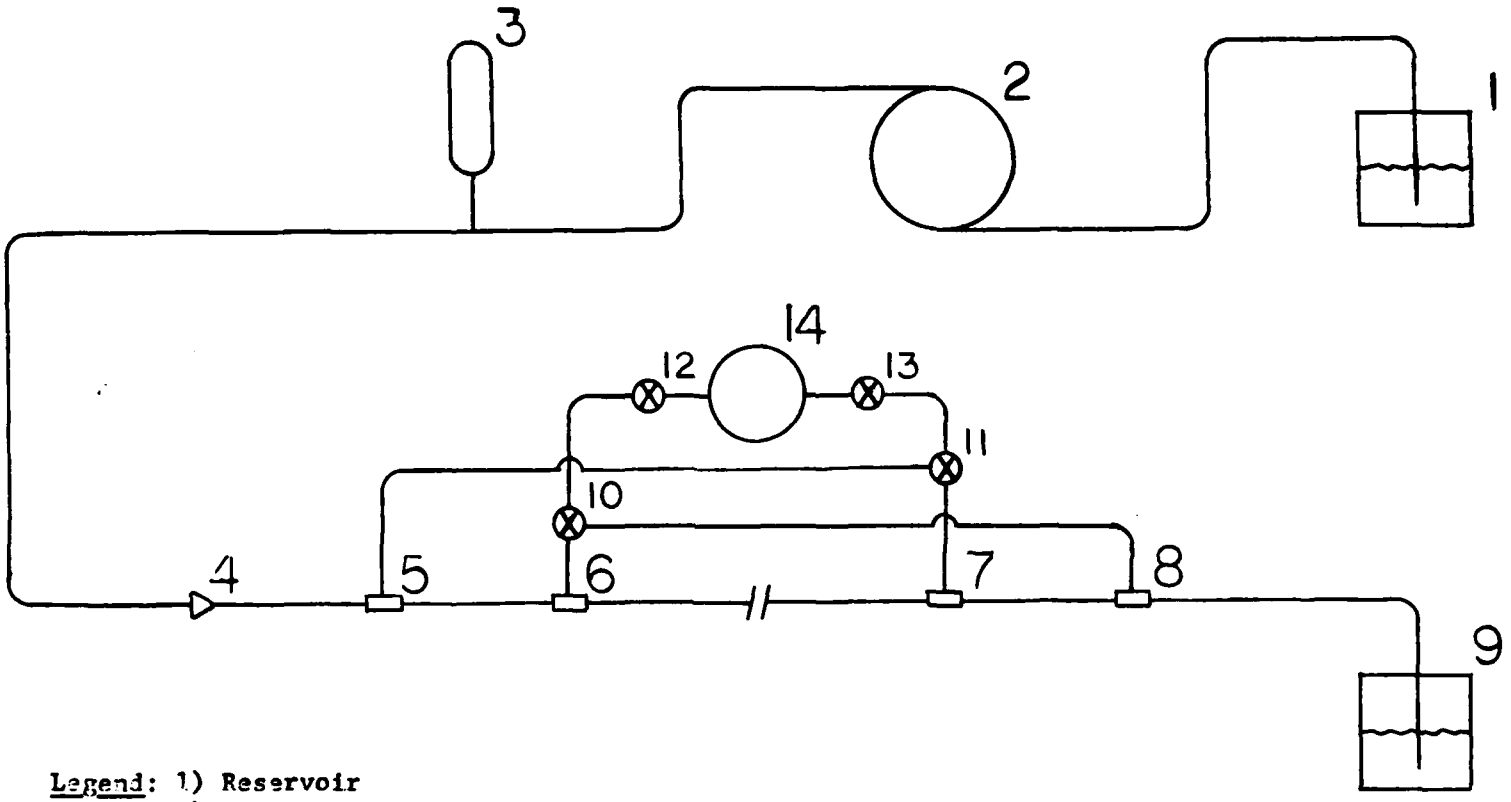
Increase the pump speed and repeat the process for the next shear rate until the entire range of shear rates is covered. A typical run takes approximately 45 minutes to complete.

The pressure drop between points 7 and 8 (P800) is divided by the pressure between locations 5 and 6 (P200). The resulting ratio is then plotted against shear rate.

TEST RESULT.

From a practical point of view, this system could not be operated below an 8V/D of 800 sec^{-1}. The pump's output was unstable at the lower settings and, even with the accumulator, a steady stream could not be obtained. Also, the pressures below 800 sec^{-1} were so low, the signal was only slightly greater than the noise level of the particular transducer.

A number of runs are shown in figure 11. The Jet A run, which lies at the top of the figure, demonstrates that for a Newtonian fluid the ratio does not change over the entire shear rate. The fact that the ratio is not exactly 1 is a consequence of the slight variations in tube diameter that occur during production. This particular set of data implies the inside diameter of the tubing between points 7 and 8 is slightly smaller than between points 5 and 6.



Legend: 1) Reservoir
2) Peristaltic Pump
3) 250 ml accumulator
4) Reducer, begin capillary tube, L/D = 0
5) Pressure tap, L/D = 150
6) Pressure tap, L/D = 250
7) Pressure tap, L/D = 750
8) Pressure tap, L/D = 850
9) tube output, L/D = 1,000
10, 11) Switching valves
12, 13) Transducer drain valves
14) Pressure transducer

85-1-10

FIGURE 10. SCHEMATIC OF CAPILLARY TUBE EXPERIMENTS

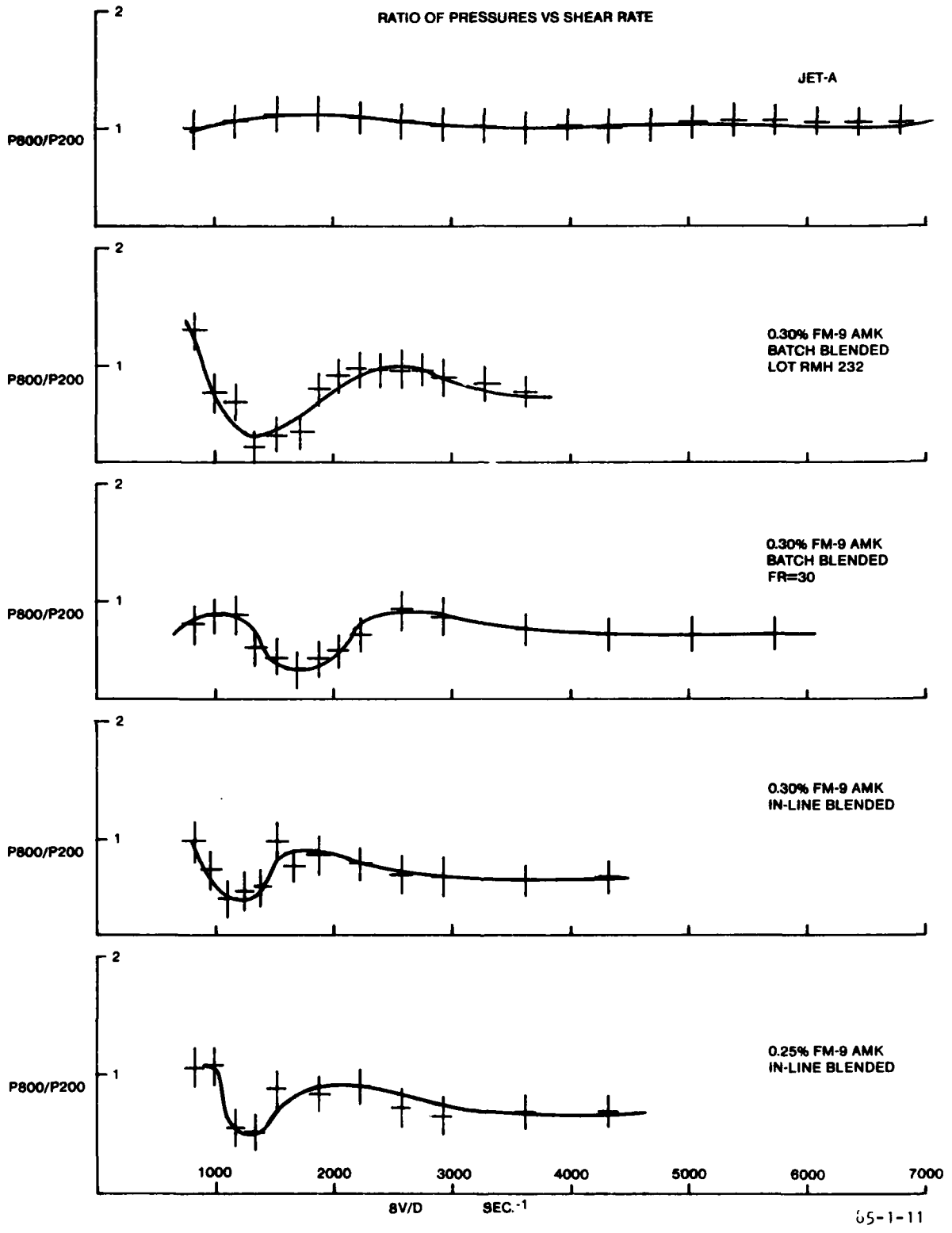


FIGURE 11. CAPILLARY TUBE EXPERIMENT RESULTS. PRESSURE AT L/D = 800 DIVIDED BY THE PRESSURE AT L/D = 200 VERSUS SHEAR RATE

The first AMK run used a sample of batch blend fuel provided by ICI (lot #RMH 232). The sample had a polymer concentration of 0.30 percent weight/weight. The most prominent feature observed is a valley centered around 1300 sec^{-1} followed by a peak centered about 2800 sec^{-1}. The ratio of pressures gradually tapered off and appeared to be stabilizing when the test was terminated. At the higher shear rates, the total pressure drop across the capillary tube would reach approximately 60 psig and the tubing in the peristalic pump would separate from the fittings on the accumulator. Each of the following runs was terminated for the same reason.

The second AMK run shows the same sample after it was partially degraded by passing it through the system three consecutive times at a shear rate of approximately 4000 sec^{-1}. Once again there is a valley and a peak. The valley shifted to about 1800 sec^{-1} while the peak remained stationary. Since the fuel was partially degraded, the total pressure did not exceed the tubing restrictions until the ratio had stabilized at approximately 0.7 over an extended range of shear rates.

The third sample was inline blended AMK which had equilibrated over several days. Once again the concentration was 0.3 percent; in this case, the valley fell at approximately 1300 sec^{-1}. The peak was at 1900 sec^{-1}. The last test sample had a 0.25 percent concentration which was obtained by diluting a sample of the inline blended fuel and allowing it to equilibrate. The valley for this sample was at 1300 sec^{-1}, as for the other undegraded samples of AMK; but it was not as deep. The peak occurred at 1900 sec^{-1} as in sample number 3. Also, this sample did not begin to show changes in the ratios until 1000 sec^{-1}, implying it was not shear thickening at 800 sec^{-1} as were the 0.30 percent blends.

At the higher shear rates, it would require extended periods of time for the pressure readings to stabilize. Also, the stream emerging from the capillary tube could be handled without wetting the surface of the object touching it for approximately 2 seconds. It is possible that the stream would maintain its integrity along the pressure fitting which would retard the response of the pressure measuring system. This phenomenon appears to be related to the establishment of a stabilized gel structure which does not relax immediately after removing the shear stress.

CONCLUSIONS

DIE SWELL EXPERIMENTS.

In these experiments, the ability of the die swell meter to be used as a quality control device was investigated. A number of blends with known concentration were tested and curves were generated from the data which relate the percent concentration of FM-9 to the pressure drop in the capillary tube and the jet diameter. With these curves, an estimate of the actual concentration can be made, providing the same slurry and base fuel are used. When other base fuel or slurries are used, the reading obtained is called the effective concentration. This effective concentration relates the rheological behavior of an unknown blend to the behavior of the blends which were made at the FAA Technical Center using 16-95 slurry and its Jet A. A plot of the effective concentration versus the exit velocity of the FAA Wing Spillage test was made. Over the range of conditions tested, a linear relationship exists between the effective concentration and the pass/fail boundary on the Wing Spillage Facility. This curve is accurate to within 10 knots when predicting the point where a failure would occur on the Wing Spillage Facility, no matter which slurry or base fuel was used to make the AMK.

Estimates of the normal stresses were calculated using the equations derived by Metzner (references 3 and 4). The normal stresses calculated using these equations ranged from 1,000 to 10,000 pa; for shear rates from 4409 sec^{-1} to 8450 sec^{-1} approximately an order of magnitude greater than the shear stresses.

Comparison of the actual concentration to filter ratio data, cup data, and nephelometer data at 30 minutes after blending showed the following: filter ratio versus concentration was linear, but this curve was slurry-dependent and the data had large amounts of scatter; cup data are ineffective as a measure of quality control, since they remained constant over a broad range of polymer concentrations; the nephelometer data had too much scatter to provide any indication of polymer concentration.

In summary, the die swell meter provides a measurement of the properties which relates to fire protection and, in turn, is effective in determining the quality of an AMK blend.

CAPILLARY TUBE EXPERIMENTS.

There is some evidence that the peaks and valleys associated with the capillary tube experiments are related to concentration and partial degradation, but there are insufficient data to draw firm conclusions. Due to the extended period of time necessary to operate the apparatus and reduce the data, no attempt was made to provide the necessary statistical base. Future investigations may look into the location of the valley along the shear axis as a basis for determining small amounts of polymer degradation and the depth of the valley as an indication of polymer concentration.

The one firm conclusion which can be drawn from the data is that the behavior of the AMK continues to change along the length of the capillary tube. The gradual stabilization of the pressure ratios versus shear rate cannot be explained by degradation alone, since the degraded sample shows similar behavior, but appears to be related to the development of a stabilized flow field which maintains its integrity as long as shear is maintained. The time dependent behavior of AMK would tend to make viscosity measurements difficult.

REFERENCES

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2. Yavrouian, A. H., et.al., Antimisting Kerosene: Base Fuel Effects; Blending and Quality Control Techniques, Jet Propulsion Laboratory, Report No. DOT/FAA/CT-83/36, 1983.

3. Sherter and Metzner, Fourth International Society of Rheology, pp. 603-618 1963.

4. Mannheimer, R., Shear and Normal Stress Measurements of Antimisting Kerosene at High Shear Rates, Parts I and II, Ninth International Congress of Rheology, Southwest Research Institute, October 1984.

5. Matthys, E. F., A Viscometric Study of the Gelation Phenomenon for Polymer Solutions in Kerosene, Ninth International Congress of Rheology, California Institute of Technology, October 1984.

6. Salmon, R. F., Wing Spillage Tests Using Antimisting Fuel, Federal Aviation Administration Technical, Report No. DOT/FAA/CT-81/11, February 1981.

APPENDIX A

DIE SWELL PROCEDURES

1. Remove the cover from the unit. Place a pail under the drain.

2. Put the hydraulic reservoir in place and fill it with filtered hydraulic fluid. Cover the reservoir with aluminum foil.

3. Put the AMK reservoir in place and secure it. Keep the the reservoir covered as much as possible.

4. Place the sensor assembly in the track.

5. Secure all electrical connections.

6. Adjust the zero reading.

7. If you cannot zero the unit, it is necessary to clean the glass surfaces of the sensor, loosen the Allen screws on the right hand face of the sensor. Use an alcohol swab to clean the surfaces. Reassemble the sensor. Use caution when securing the Allen screws--the body is made of aluminum.

8. Put the span unit in the sensor. Keep the span unit in the green area. Adjust the reading to 5.99 mm.

9. Repeat steps 6 and 8 as necessary.

10. Put the capillary tube in place and carefully align the sensor. Lock the sensor in place (large Allen screw on the bottom surface). Gently secure the cat's eye clamp. There should be enough adjustment to either cover the tube with the sensor unit or have the tube completely uncovered.

11. Check the sensor calibration by running the sensor over the capillary tube. At least 1 cm of the tube should be in the sensor. It should read 3.275 mm ± 0.005 mm.

12. Make sure the tube is 1 mm from the sensor. To do this, turn the adjustment knob so that the unit just begins to sense a change from zero. Back off 1 small division (i.e., 1 mm).

13. Pour about one liter of the test sample in the reservoir. Open both valves. Allow enough sample to discharge so that the air is purged from the lines. Close the valve to the capillary tube.

14. Set the pump speed to 10. Start the pump in Neutral (Neutral is the center position). Load the cylinder by placing the pump in reverse (move the handle to the right). After the mark appears in the sight glass, put the pump in Neutral. The pump may be left in Neutral for a limited period of time. DO NOT allow the reservoir to run dry.

15. Select your flow rates and shear rates from the chart in the drawer. Set the pump speed to the starting position. If the tube is horizontal, start with a shear rate greater than 4000 sec^{-1} so that the jet does not droop below the green area.

16. Check your voltage settings on the die swell unit and the strip chart.

17. Record all the data on the strip chart including the date, time, fuel type, and voltage/scale settings.

18. Close the valve to the reservoir and open the valve to the capillary tube.

19. Start the run by moving the pump control lever to the left. After making the reading, you may change the pump speed as the pump is moving. Do not exceed the cylinder limitations. This may take as little as 15 sec. at the higher flow rates. Record the die swell indication.

20. To reload the system, drop the pump speed to 10. Close the capillary tube valve and open the reservoir valve. DO NOT draw air into the system.

21. Repeat steps 18 through 20 for all the points selected in step 15.

22. At the end of the run, pump all fuel from the cylinder by going full forward. Open the reservoir valve and allow the sample to drain out.

23. Remove the reservoir and capillary tube. Cap the fittings and clean the tube and reservoir.

24. Turn off all power. If the unit will be idle for an extended period of time; remove the hydraulic reservoir and cap the line, and secure the cover.

25. Reduce the data according to the following procedure. Some key parameters are listed below:

ρ AMK = 0.808 gm/cm^3 @ 15°C

$\overline{D}$ = 2.90 mm (used for 8V/D cal.)
L/R = 191
D = 2.94 mm (used for die swell calculations)
8V/D = 6.68Q where Q is ml/min
8V/D is sec^{-1}
τ_{12} = 180.3 ΔP where ΔP is psig
τ_{12} is $dyne/cm^2$

a) Determine the total pressure drop based on the strip chart reading.

b) Determine Q based on the calibration sheet.

c) Calculate 8V/D by multiplying Q by 6.68. The units are sec^{-1}.

d) Calculate τ_{12a} the apparent wall shear stress, by multiplying the total pressure drop by 180.3. The units are dynes/cm^2. Divide by 10 to get Pa.

e) Read D_j off of the strip chart or by recording the indicator readings. If you record the indicator readings, cross check with the strip chart.

f) Calculate D_j/D by dividing D_j by 2.94 mm. The result is dimensionless.

g) Plot D_j/D vs. 8V/D on semi-log paper. Use this for comparison purposes.

h) Plot τ_{12a} vs. 8V/D on a log log scale. This shows the linear area for calculating n'.

i) If available, determine the corrected pressure drop of the different shear rates. To do this, plot the pressure drop for a number of tube lengths (L/R = 200, 300, and 400) for a given radius and shear rate. Determine the end correction by plotting the y-intercept of the data. The corrected pressure drop is:

$$P_c = \Delta P - P_e$$

where P_c is the corrected pressure

P_e is the end correction

Correct P_c for inertial effects by subtracting 1.1 ρV^2,

$$P = P_c - 1.1\rho V^2$$

j) An alternate is to use the wall shear stress technique developed at the Technical Center. In this case,

P = the pressure measured across the two taps (psid) and
$\tau_{12} = 180.3\ P_2$ (dyne cm^2), for L/R = 191, r = 2.90

Generally, $\tau_{12} = \frac{P}{A_w}$

where A_w is the area of the tube wall.

k) Plot τ_{12} vs 8V/D on log log paper.

$$n' = \frac{d \log \tau_{12}}{d \log 8V/D}$$

An easy way to calculate n' is to do a linear regression over the linear region determined above. The slope is n'.

l) Calculate $\dot{\gamma}_R$ the corrected shear rate:

$$\dot{\gamma}_R = \left(\frac{3 + 1/n'}{4}\right)\left(\frac{8V}{D}\right)$$

m) Calculate n

$$n = \frac{d \log \tau_{12}}{d \log \dot{\gamma}_R}$$

n) Calculate $(\upsilon_{11} - \upsilon_{22})\Big|_{\dot{\gamma}}$ the normal stress for a given shear rate using:

$$(\upsilon_{11} - \upsilon_{12})\Big|_{\dot{\gamma}} = \frac{\rho D^2 (8V/D)^2}{64n'}\left\{(n' + 1)\left(\frac{3n + 1}{2n + 1}\right)^2 \left(\frac{D}{D_j}\right)^2 \left(n' + 1 + \frac{d \log D/D_j}{d \log 8V/D}\right)\right\}$$

o) Plot τ_{12} and $\upsilon_{11} - \upsilon_{22}$ on a log log scale vs $\dot{\gamma}_R$.

p) The intrinsic viscosity for a given shear rate is:

$$\eta = \frac{R\ P/2L}{\dot{\gamma}_R} \quad \text{or} \quad \frac{D\ P/4L}{\dot{\gamma}_R}$$

APPENDIX B

SPECIFICATIONS FOR LABORATORY-SCALE ANTIMISTING KEROSENE BLENDING DEVICE

This document describes the recommended system and procedure for the design and operation of a standard, laboratory-scale antimisting kerosene (AMK) blending device for FM-9 slurry and Jet-A fuel.

During the evaluation of the existing FM-9 slurry, several mixing systems have been designed and operated with varying degrees of success. This specification is not intended to imply that this is the only system that will produce acceptable AMK. However, in an effort to standardize procedures and control variables, the following system is recommend.

PARTS LIST.

1. Cole-Parmer Inst. Co. Model No. 7520-20 Masterflex™ Progressive Cavity pump with Model No. 7017-21 Head 0-600 RPM, 10-turn potentiometer speed adjustment.

2. Cole-Parmer Inst. Co. Tygon™ Special Tubing, Cat. No. K-6401-47 (This exact tubing must be used for proper pump performance.)

3. Chemineer-Kenics Static Mixing Tube, Part No. 37-04-112 1/4" diameter 27 element 9-1/4" length stainless steel mixing tube.

4. Standard 50 cc syringe with "luer lok" tip.

5. Luer female coupling.

6. 3/8" "swagelok" union modified to accept Luer female coupling.

7. 3/8" "Whitey" Ball Valve.

8. Fuel Supply Container - approximately 5 liters.

9. AMK Catch Container - Clear Glass.

Assemble the above per figure B-1.

DISCUSSION.

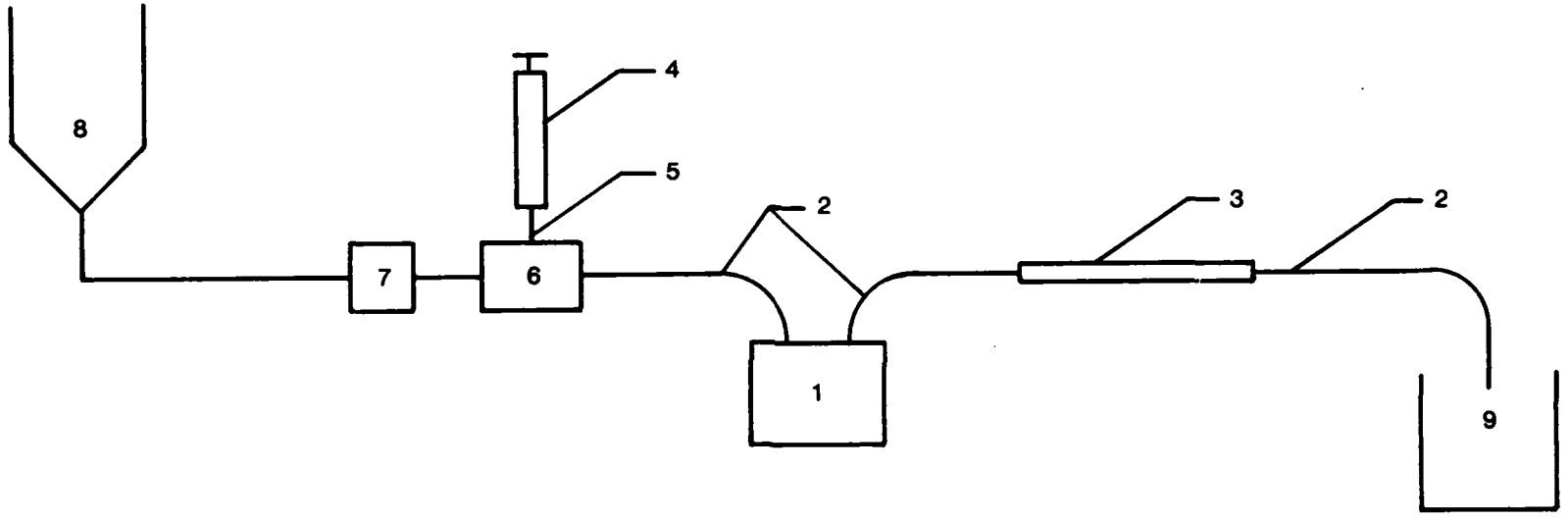
The Masterflex progressive cavity pump is specified because of the gentle pumping action provided by the type of pump. This permits more precise control of blending by eliminating any unknown mixing action provided by the pump itself, thus focusing the majority of mixing in the mixing tube above.

PROCEDURE.

1. Measure desired quantity of Jet A into supply container (standard quantity is 3.5 liters).

2. Calculate the required quantity of slurry for the above quantity of Jet A (standard quantity is 0.0249 grams for 25 percent solids slurry).

ANTIMISTING FUEL LABORATORY BLENDER



NOTE:

TUBE LENGTH 6-3 20"

TUBE LENGTH 3-9 15"

TUBE LENGTH 8-7-6 NO SPEC.

TUBE SIZE 8-7-6 3.8"

COMPONENTS

1. PUMP
2. TYGON TUBING
3. STATIC MIXING TUBE
4. SYRINGE
5. COUPLING
6. SYRINGE MOUNT
7. BALL VALVE
8. SUPPLY CONTAINER
9. CATCH CONTAINER

FIGURE B-1. SCHEMATIC OF LABORATORY SCALE BLENDER FOR ANTIMISTING KEROSENE

3. Weigh empty syringe.

4. Carefully load syringe and weigh, adjusting to obtain required quantity.

5. Assemble syringe to fitting.

6. Start Masterflex pump (standard setting is 1.0 ℓ/min).

7. Immediately begin injecting slurry at as constant a rate as possible. Slurry should be injected over the entire Jet A flow time, leaving only enough Jet A to purge system after depletion of slurry (standard injection time is approximately 200 seconds).

8. Material in catch container should not be disturbed until visually clear.

APPENDIX C

BLENDER DESCRIPTION

GENERAL.

Antimisting kerosene (AMK) is produced in this blending sevice (figure C-1) by the controlled introduction of AMK additive slurry into a metered Jet A stream. A series of 2 static mixing tubes disperse the slurry uniformly into the fuel stream, permitting the polymer to swell and subsequently dissolve into the Jet A.

MIXING PRINCIPLE.

Blending of the FM-9 polymer into Jet A to produce AMK occurs during two distinct phases, dispersion and dissolution. During the dispersion phase, slurry containing FM-9 polymer is introduced into the Jet A base fuel. Static mixing tubes are used in this blending device to disperse the slurry. Other dispersion techniques (power mixers, vortex mixers, homogenizers, etc.) can also be used but have not been thoroughly evaluated to date. Static mixing tubes rely on a combination of high fluid Reynolds number and fluid residence time to thoroughly mix (disperse) diverse materials into a homogenous fluid. The degree of dispersion achieved by the static mixing tubes directly affects the polymer's ability to dissolve in the base fuel and is, therefore, an important factor contributing to final fuel quality.

The dissolution phase takes place after the polymer has been dispersed in the base fuel. Dissolution is a function of the polymer chemistry and is, therefore, affected by other factors such as ambient temperature, fuel aromatic and water content, and time.

Sample of fuel taken from the blender can exhibit changing characteristics (clarity, viscostiy, etc.) for many hours after blending. Changing clarity will become immediately apparent to the blender operator.

Samples of fuel taken immediately from the blender will be cloudy, almost opague, but will clear considerably within 15 minutes. This is a gross example of polymer dissolution.

FLUID METERING SYSTEMS

SLURRY METERING.

Because of the large, Jet A to slurry volume and viscosity ratios, an extremely precise method of controlli g the flow of these components must be utilized. Small changes in slurry flow will result in wider variations in AMK concentration.

To insure precise flow control, a variable speed progressive cavity pump is used to pump and meter the slurry. This pump is similar in principle to a basic screw pump, but includes a special close tolerance rotor and stator that insures a non-pulsing, precisely metered flow rate up to an outlet pressure of 170 psi. This type of pump is also a low shear device which causes little or no polymer degradation.

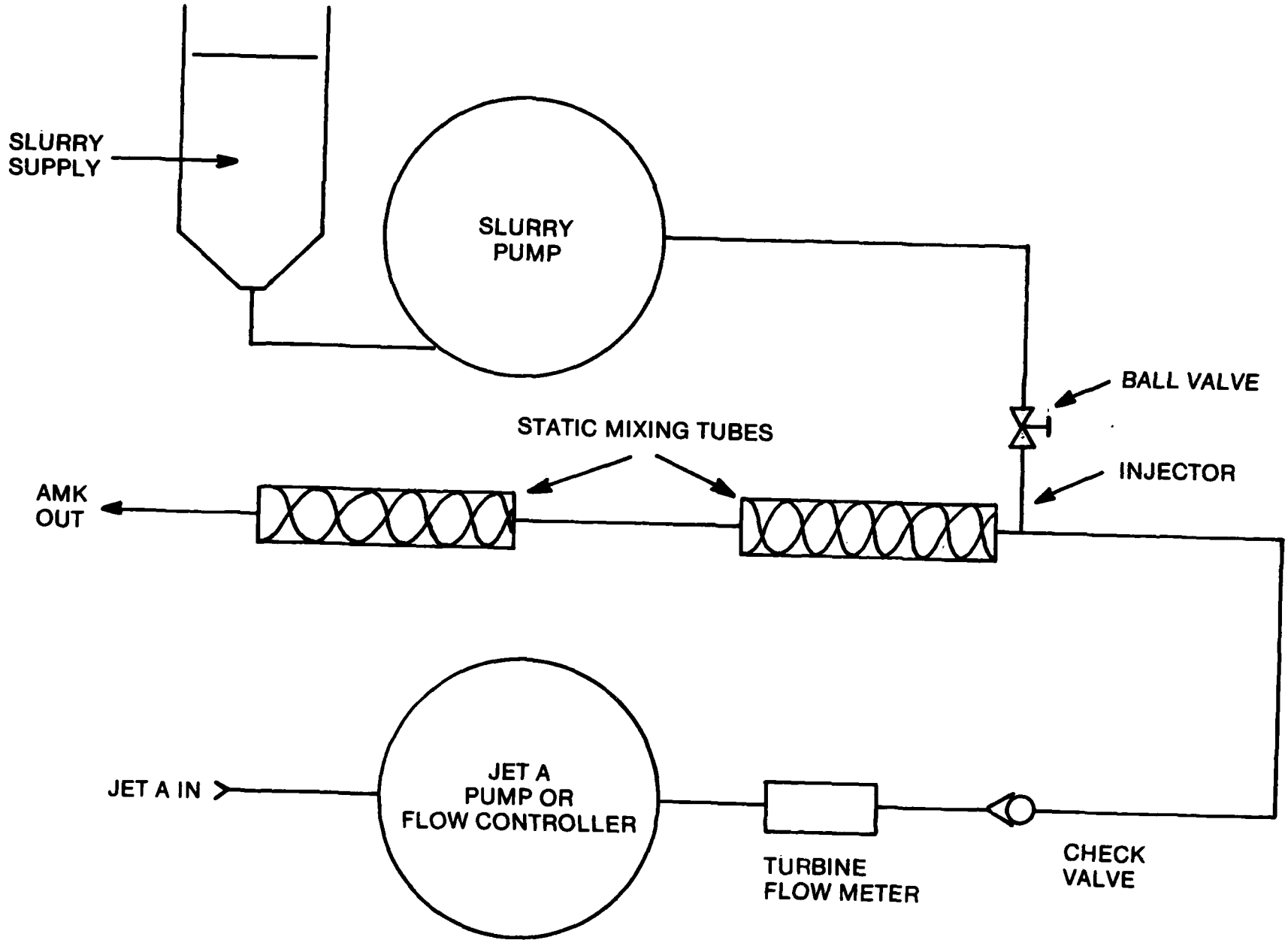


FIGURE C-1. SCHEMATIC OF LARGE SCALE BLENDER

Metered slurry is injected into the Jet A stream immediately upstream of the static mixing tubes. Slurry injection is parallel to and in the same flow direction as the Jet A. A manual valve is used to prevent Jet A from backing up into the slurry line and pump during startup and shutdown of the blending unit. Slurry is gravity fed to the inlet of the metering pump from the stainless steel hopper.

JET A METERING.

Jet A is supplied to the blender by an external Jet A pump. This pump must be supplied by the contractor. The pressurized fuel is supplied to the inlet of the rated flow control device. This unit automatically adjusts to changes in system and inlet pressures to assure a constant preset flow rate. The flow rate is controlled by turning the set point knob on top of the controller. Refer to the calibration curve provided with the unit.

BLENDER SITE REQUIREMENTS.

The following must be available at the blender site:

1. Power: 115 vac 60 Hz 15 amps
2. An area approximately 15' x 15' suitable for safe operation
3. Jet A source:
   (a) Delivery system capable of 50 to 100 gpm and 60 psi minimum
   (b) Flow measurement to 0.5%
   (c) Filter/Coalescer in-line
4. 50-gallon waste drum(s)
5. Oil absorbent material
6. Wash water available close by

BLENDER SETUP.

1. Carefully uncrate blender, saving all packing material.
2. Forklift blender to site, placing it within reach of 50' delivery hose.
3. Connect Jet A suply.
4. Connect to 115 VAC.
5. Unreel 50' delivery hose.
6. Connect slurry delivery hose to slurry pump.
7. Attach injector to slurry deliver hose.

PRECONDITIONING OF SLURRY.

AMK slurry can exhibit a tendency to separate into layers of differing viscosities over a period of time (rate of separation is unknown). Therefore, immediately prior to use, the slurry should be thoroughly mixed to eliminate any nonuniformity. This mixing is a time consuming operation in its present form, and adequate time must be allowed prior to blending to make sure that enough preconditioned slurry is on hand to complete the desired quantity of fuel. Care must be taken during the mixing operation to prevent contaminants such as dirt, water, Jet A fuel, and other hydrocarbon solvents from contacting the slurry, slurry containers, mixing equipment, hands, etc. Preconditioning procedure is as follows:

1. Wear coveralls or suitable clothing and gloves.
2. Obtain a clean, 5-gallon plastic pail.

3. Open slurry container and pour approximately 1/2 of the slurry material in clean pail.
4. Manually stir and break up thick material remaining in original pail.
5. Add remaining material to clean pail, making sure all material is removed from original container. Wash and dry container and lid.
6. Mechanically or manually mix material until smooth and uniform (10 to 15 minutes).
7. Place screen lid on original pail.
8. Pour stirred material through screen into original container and seal container.
9. Wash and dry screen, extra pail, mixing tools, etc.
10. Slurry is now ready for use.

STARTUP PROCEDURE.

I. Priming Slurry Pump

1. Insure that all fittings are tight.
2. Pour slurry into stainless steel hopper (approximately 5 gallons).
3. Place slurry delivery hose into waste container.
4. Start pump, set dial at 2.5.
5. Slurry should begin flowing within 5 seconds. If not, stop pump and look for blockage. (Make sure valve at end of slurry delivery hose is OPEN.)
6. Run slurry into waste container until it flows freely and uniformly.
7. Place slurry delivery line into hopper for recirculation, allow 15 minutes for pump to warm up and stabilize.
8. Pump is now ready for calibration.

II. Jet A Flow Rate Setting

Determine desired Jet A flow rate. This blender is capable of operating from 50 to 100 gpm.

Consult graph supplied with the regulating valve to determine controller setting for desired flow rate. Set the pointer on top of controller for this flow setting.

III. Slurry Calibration Procedure

To determine the proper slurry flow rate for a desired total AMK rate, perform the following calculation:

$$F = \frac{C \times A \times B \times E}{(D-C)}$$

where:

*A = AMK flow rate, gallons per minute
B = Specific weight of Jet A = 6.74 lb/gallon (ambient temperature)
C = Desired concentration, i.e., 0.30% = 0.003
D = Slurry polymer loading (from manufacturer's analysis)
E = Conversion, lbs. to grams = 435.6 gms/lb
F = Slurry flow rate, grams per minute

1. Using the above formula with the exact slurry/polymer loading, calculate the mass slurry flow rate.

2. Carefully weigh plastic beaker.
3. Place slurry injector tube in hopper and open manual valve.
4. Start pump and adjust variable speed drive to a setting of 2.75.
5. Place clean plastic beaker under injector tube and catch slurry for precisely 1/2 minute. Weigh slurry output.
6. Adjust slurry pump to obtain proper slurry output if number obtained in step 5 is incorrect.
7. Repeat until slurry output is within 10 gm. of calculated value.
8. Repeat at least 3 times to insure repeatability.
9. Slurry pump is now properly adjusted and ready for use.

*50, 75, 100 GPM

IV. Startup

1. Remove slurry delivery hose and injector tube. Rinse with water and air dry.
2. Attach slurry delivery hose to slurry pump.
3. Attach injector to slurry delivery hose.
4. Install injector (make sure manual valve is closed).
5. Place outlet nozzle into product tank (wing, drum, fuel tank). [note: initial product (2 to 3 seconds) should be discarded]
6. Open nozzle.
7. Start Jet A flow.
8. Wait until Jet A flow is flowing full (2-3 seconds).
9. Start slurry pump. When slurry fills the slurry delivery hose, open manual valve.
10. Blender is now making AMK.
11. Replenish slurry in hopper as required.

Shutdown

1. Close manual valve in slurry line while turning pump off.
2. Close outlet nozzle.
3. Shut off Jet A supply system.
4. Disconnect slurry delivery line and the manual valve.
5. Pump remaining slurry into original container.

Cleaning Procedure

Immediately after blending, it is necessary to remove and clean the slurry injection assembly. To clean this assembly, flush hose, valve, and injector with water. Disassemble the injector and valve assembly and clean out. If any residue remains in the injector, soak the unit in solvent (Inhibisol™) and scrub until clean. Air dry component and reassemble.

Water is the only solvent to be used in the slurry system upstream of the manual valve on the slurry outlet line. Slurry supply cylinder, interconnecting tubing, and slurry pump should be flushed with clean water after each use. Operate pump while keeping slurry cylinders supplied with clean water until the output of the pump runs clear. This will do a thorough job of cleaning the internal parts of the pump, eliminating the need for disassembly. Shut off water supply and allow

pump and tubing to drain. Do not run pump dry. Seal the pump inlet and outlet by closing the slurry valves (beneath the slurry cylinders) and the manual valve on the slurry outlet line.

NOTE: Both the slurry system and the Jet A system must be completely drained before shipment.

2. Carefully weigh plastic beaker.
3. Place slurry injector tube in hopper and open manual valve.
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5. Place clean plastic beaker under injector tube and catch slurry for precisely 1/2 minute. Weigh slurry output.
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9. Start slurry pump. When slurry fills the slurry delivery hose, open manual valve.
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Shutdown

1. Close manual valve in slurry line while turning pump off.
2. Close outlet nozzle.
3. Shut off Jet A supply system.
4. Disconnect slurry delivery line and the manual valve.
5. Pump remaining slurry into original container.

Cleaning Procedure

Immediately after blending, it is necessary to remove and clean the slurry injection assembly. To clean this assembly, flush hose, valve, and injector with water. Disassemble the injector and valve assembly and clean out. If any residue remains in the injector, soak the unit in solvent (Inhibisol™) and scrub until clean. Air dry component and reassemble.

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pump and tubing to drain. Do not run pump dry. Seal the pump inlet and outlet by closing the slurry valves (beneath the slurry cylinders) and the manual valve on the slurry outlet line.

NOTE: Both the slurry system and the Jet A system must be completely drained before shipment.

APPENDIX D

DIE SWELL DATA REDUCING AND PLOTTING PROGRAM FOR HP-9830

The program used to reduce and plot the die swell data is an adaptation of the polynomial regression program found in the HP-9830 Math Pack Manual. The program performs the following, in the following order:

1. Prints the axes, labels and numbers them.

   i.e., For the input ot "YMIN, YMAX, INGRM," the input of 2, 4, 1 means the the Y axis will be set up and numbered from 10^2 to 10^4 with numbering at 10^3 and 10^4. "XMIN, XMAX, INCRM" of 3, 4, 1 starts at 10^3, ends 10^4 with one label.

2. Stores and prints the die swell test data input via the keyborad.

3. Calculate and prints τ_{12a} and the die swell ratio.

4. Determines n' by a point-to-point slope analysis. Uses n' to determine $\dot{\gamma}_R$.

5. Calculates and prints the values for τ_{12} versus $\dot{\gamma}_R$ Determines and plots the first order least squares curve fit for these points and stores the slope, n.

6. Prints the values for reciprocal die swell ratio versus 8V/D. Determines a second order curve fit for these points and stores the coefficients for use in determining the slope for use in determining $\nu_{11} - \nu_{22}$.

7. Prints the values for $\nu_{11} - \nu_{22}$ versus $\dot{\gamma}_R$, plots the data points, determines a second order curve fit for the points, and plots the curve fit.

8. Enables manual writing of the plotter heading at the conclusion of the program.

9. The program is dependent on the transducer and capillary tubes discussed in this report, but it can be adapted to other tubes and transducers.

PROCEDURES FOR RUNNING THE HP-9830 DIE SWELL DATA REDUCING AND PLOTTING PROGRAM

1. Load the program from the tape into the memory of the HP-9830.

2. Place a sheet of log-log paper on plotter. Set the X axis for one cycle and the Y axis for two cycles. (It may be necessary to set Y to three cycles if $\tau_{12a} < 100.$)

3. Run program.

4. Enter 3, 4, 1 when "XMIN, XMAX, INCR" appear.

5. Enter 2, 4, 1 when "YMIN, YMAX, INCR" appear if using 2-cycle paper. Enter 1, 4, 1 for 3 cycle paper.

6. When "Number of Sets of Data" appears, enter the number of runs to be plotted on this particular plot.

7. Enter 1 if the kinetic energy effects are to removed (i.e., if the wet/dry transducer is used).

8. When "Number of Points" appears, enter the number of data points for that run.

9. Enter values for 8V/D, number of division on the 5V scale, and the jet diameter.

10. If mistakes were made when entering the data, enter 1 and re-enter correct data; if not enter 0.

11. When plotter is finished plotting $\nu_{11} - \nu_{22}$, switch pens and proceed as in steps 7 - 10.

12. Continue procedures as in steps 7 - 11 until all the runs are plotted.

13. Enter 1.7 for character height and 0 degrees for angle. Move the plotter pen to correct position by use of the display keys. When the pen is in the correct position, type the heading via the keyboard. When the heading is completed, press the stop button.

```
10 DIM C[66],B[11]
11 DIM G[19],H[19]
12 DIM O[19]
20 FOR I=1 TO 11
30 C[I]=B[I]=0
40 NEXT I
50 FOR I=12 TO 66
60 C[I]=0
70 NEXT I
80 B[1]=1
90 W=N=S1=S2=S3=S4=S5=0
110 D2=2
120 IF D2>9 THEN 100
130 DISP "XMIN,XMAX,INCRM.=";
140 INPUT X1,X2,X3
150 DISP "YMIN,YMAX,INCRM.=";
160 INPUT Y1,Y2,Y3
170 I=(X2-X1)/27
180 J=(Y2-Y1)/17
190 Y5=Y1-2*J
200 Y6=Y2+J
210 SCALE X1,X2+0.001,Y1,Y2+0.001
220 XAXIS Y1,X3,X1,X2
230 YAXIS X1,Y3,Y1,Y2
240 GOSUB 380
270 Z=FNK0
280 LABEL (*,3,1,0,2/3)
285 DISP "NUMBER OF SETS OF DATA";
286 INPUT N8
290 GOSUB 550
300 P9=1
310 IF P9#1 THEN 350
320 PRINT
330 PRINT "PT.NO."TAB14"X"TAB28"Y"
340 PRINT
350 RETURN
360 END
370 FORMAT 2F7.2
380 LABEL (*,1.7,0.7,0,2/3)
390 FOR I=Y3+Y1 TO Y2 STEP Y3
400 PLOT X2/100,I,1
410 CPLOT 0,-0.65
420 LABEL (*)10↑I
425 LABEL (*)" PA"
430 NEXT I
435 PLOT 3.3,Y1+0.02,-1
436 LABEL (*)"1/SEC"
437 PLOT 3.3,2.4,1
438 LABEL (*)"T   VS."
439 CPLOT 1,0
440 LABEL (*)"12"
441 PLOT 3.15,3.3,1
```

```
442 LABEL (*)"V  - V   VS."
443 CPLOT 1,0
444 LABEL (*)"11   22"
449 DEG
450 LABEL (*,2,2,90,3/2)
460 FOR I=X3+X1 TO X2 STEP X3
470 PLOT I,Y2/100,1
480 CPLOT -0.1,0
490 LABEL (*)10↑I
500 NEXT I
510 RETURN
550 FOR N7=1 TO N8
551 DISP "INPUT 1 FOR K.E. CORRECTION";
552 INPUT Q5
555 GOSUB 5000
685 GOSUB 300
690 M6=1
691 D1=1
695 FOR Q1=2 TO (H[1]+1)
696 IF Q5=1 THEN 699
697 K4=0
698 GOTO 700
699 K4=H[Q1]↑2*1.2E-04
700 Y=(382.3*G[Q1]-K4)/382.3
701 O[Q1]=1/O[Q1]
703 GOSUB 9500
705 B[2]=(3+(1/N2))*H[Q1]/4
710 GOSUB 1760
715 NEXT Q1
725 GOSUB 1000
730 GOSUB 3000
735 N1=B[2]
737 GOSUB 4000
740 GOSUB 9000
745 GOSUB 300
750 M6=0
755 FOR Q1=2 TO (H[1]+1)
760 Y=O[Q1]
765 B[2]=H[Q1]
770 GOSUB 1760
775 NEXT Q1
780 D1=2
785 GOSUB 1000
790 GOSUB 3000
795 B2=B[3]
800 B1=B[2]
805 GOSUB 9000
810 GOSUB 300
815 M6=1
819 FOR Q1=2 TO (H[1]+1)
820 IF Q5=1 THEN 823
821 K4=0
```

```
822 GOTO 824
823 K4=H[Q1]↑2*1.2E-04
824 GOSUB 9500
825 B[2]=(3+(1/N2))*H[Q1]/4
830 M=2*B2*LGT(H[Q1])+B1
835 Y=0.0001091*(H[Q1]↑2/N2)*((N2+1)*(N1*3+1)/
                (2*N1+1)-(O[Q1]↑2)*(N2+1+M))
840 GOSUB 1760
845 NEXT Q1
850 D1=2
853 GOSUB 1000
855 GOSUB 3000
860 GOSUB 4000
861 GOSUB 9000
863 NEXT N7
865 GOSUB 6000
870 END
1000 IF N <= D2-W THEN 1250
1030 IF D1 <= D2-W THEN 1060
1040 DISP "MAX DEG=";D2-W
1050 END
1060 IF W=0 THEN 1240
1070 T=0
1080 FOR I=1 TO D1+1
1090 B[I]=0
1100 FOR J=1 TO D1-I+2
1110 R=(I+J-1)*(D2+2-0.5*(I+J))
1120 B[I]=B[I]+C[T+J]*C[R]
1130 NEXT J
1140 T=I*(D2+(3-I)/2)
1150 NEXT I
1160 R1=0
1170 FOR I=2 TO D1+1
1180 R1=R1+C[I*(D2+(3-I)/2)]↑2
1190 NEXT I
1200 T0=C[(D2+1)*(D2+2)/2]
1210 T0=T0-C[D2+1]↑2
1220 RETURN
1230 END
1240 IF N>D2 THEN 1270
1250 DISP "NOT ENOUGH POINTS"
1260 END
1270 P=W=1
1280 D2=D2+1
1290 FOR J=1 TO D2
1300 C[P]=SQRC[P]
1310 FOR I=1 TO D2-J+1
1320 C[P+I]=C[P+I]/C[P]
1330 NEXT I
1340 R=P+I
1350 S=R
1360 FOR L=1 TO D2-J
```

```
1370 P=P+1
1380 FOR M=1 TO D2+2-J-L
1390 C[R+M-1]=C[R+M-1]-C[P]*C[P+M-1]
1400 NEXT M
1410 R=R+M-1
1420 NEXT L
1430 P=S
1440 NEXT J
1450 T=(D2+1)*(D2+2)/2
1460 FOR I=1 TO D2-1
1470 T=T-1-I
1480 C[T]=1/C[T]
1490 FOR J=1 TO D2-I
1500 P=D2+1-I-J
1510 P=P*(D2+1-(P-1)/2)-I
1520 R=P-J
1530 S=0
1540 U=I+J+1
1550 V=P
1560 FOR K=1 TO J
1570 V=V+U-K
1580 S=S-C[R+K]*C[V]
1590 NEXT K
1600 C[P]=S/C[R]
1610 NEXT J
1620 NEXT I
1630 C[1]=1/C[1]
1640 GOTO 1070
1760 B[2]=LGT(B[2])
1770 Y=LGT(Y)
1780 IF FNX1 THEN 1800
1785 RETURN
1790 END
1800 RETURN
1810 END
1820 DISP "NOT ALLOWED"
1830 END
3000 IF W=0 THEN 3110
3010 PRINT
3020 PRINT "COEFFICIENTS"
3030 PRINT
3040 FORMAT F3.0,E16.9
3050 FOR I=1 TO D1+1
3060 WRITE (15,3040)"B("I-1")="B[I]
3070 NEXT I
3080 PRINT
3090 PRINT "R SQUARE = "R1/T0
3100 PRINT
3105 RETURN
3110 END
4000 FOR X=3.55 TO 4 STEP (X2-X1)/100
4010 Y=FNZX
4020 PLOT X,Y
4030 GOTO 4050
```

```
4040 PEN
4050 NEXT X
4060 Z=FNK0
4065 RETURN
4070 END
5000 DISP "NUMBER OF POINTS?";
5010 INPUT H[1]
5020 O[1]=G[1]=H[1]
5030 PRINT "PT #   8V/D     DIV   D.S."
5040 FOR C9=1 TO H[1]
5050 DISP "8V/D, DIV, D.S.";
5060 INPUT H[C9+1],G[C9+1],O[C9+1]
5070 WRITE (15,5276)C9,H[C9+1],G[C9+1],O[C9+1]
5080 NEXT C9
5085 PRINT
5090 DISP "CORRECTIONS? INPUT 1";
5100 INPUT C8
5110 IF C8=1 THEN 5340
5120 IF Q5=1 THEN 5180
5130 F1=0.015
5140 F2=1.9981
5150 F3=0.02991
5160 F4=34.76
5170 GOTO 5220
5180 F1=0.129
5190 F2=4.9282
5200 F3=0.6336
5210 F4=17.5
5220 PRINT "PT #   8V/D     T12   DJ/D"
5230 FOR C9=2 TO (H[1]+1)
5240 G[C9]=F4*((G[C9]*0.05+F1)*F2-F3)
5250 O[C9]=O[C9]/295
5260 C6=C9-1
5270 WRITE (15,5275)C6,H[C9],G[C9],O[C9]
5275 FORMAT F2.0,4X,F5.0,4X,F4.0,2X,F6.3
5276 FORMAT F2.0,4X,F5.0,3X,F6.1,1X,F5.0
5280 NEXT C9
5285 PRINT
5290 RETURN
5300 END
5340 DISP "INPUT POINT TO BE CORRECTED";
5350 INPUT C7
5360 DISP "8V/D,DIV,D.S. ";
5370 INPUT H[C7+1],G[C7+1],O[C7+1]
5380 PRINT C7;H[C7+1];G[C7+1];O[C7+1]
5390 GOTO 5090
6000 DEG
6010 DISP "CHARACTER HEIGHT(%)";
6020 INPUT H
6030 DISP "0 DEG OR 90 DEG ?";
6040 INPUT D
6050 LABEL (*,H,0.7,D,2/3)
6060 LETTER
```

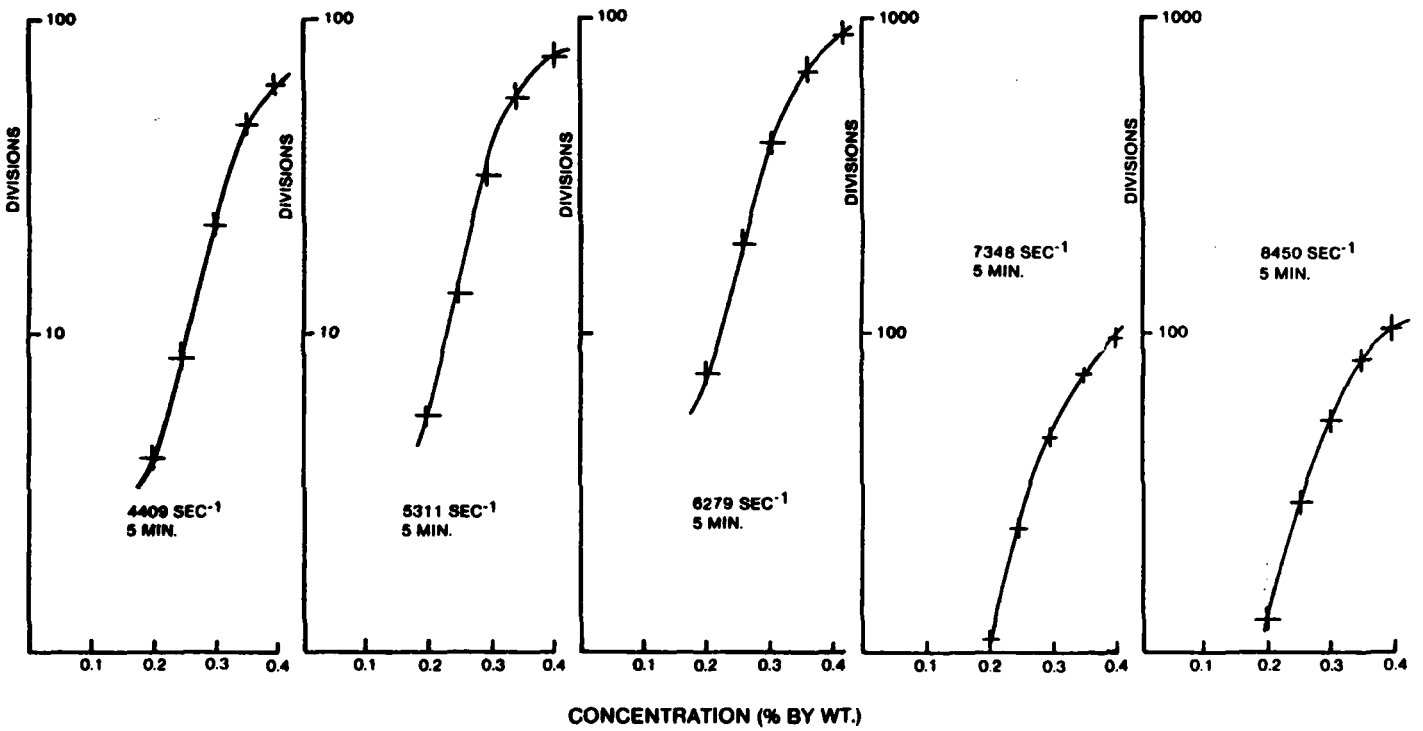
```
6070 Z=FNK0
6080 END
7000 DEF FNX(Z)
7010 FOR I=2 TO D2
7020 B[I+1]=B[I]*B[2]
7030 NEXT I
7040 B[D2+2]=Y
7050 R=0
7060 FOR I=1 TO D2+2
7070 FOR J=I TO D2+2
7080 R=R+1
7090 C[R]=C[R]+B[I]*B[J]*Z
7100 NEXT J
7110 NEXT I
7120 S1=S1+B[2]*Z
7130 S2=S2+B[2]↑2*Z
7140 S3=S3+Y*Z
7150 S4=S4+Y*Y*Z
7160 S5=S5+B[2]*Y*Z
7170 N=N+Z
7180 IF P9#1 THEN 7230
7190 IF Z#1 THEN 7240
7200 F=10↑Y
7210 E=10↑B[2]
7220 WRITE (15,7260)N,E,F
7230 RETURN FNPZ
7240 WRITE (15,7270)" DELETE"E,F
7250 RETURN FNPZ
7260 FORMAT F6.0,2F14.4
7270 FORMAT 2F14.4
7500 DEF FNK(Z)
7510 PLOT X2,Y2,1
7530 PEN
7540 DISP "DONE"
7550 RETURN 0
8000 DEF FNP(Z)
8010 IF M6#1 THEN 8080
8020 IF B[2]<X1 OR B[2]>X2 OR Y<Y1 OR Y>Y2 THEN 8120
8030 PLOT B[2],Y,1
8040 CPLOT -0.3,-0.15
8050 IF Z=1 THEN 8084
8060 LABEL (*)"X";
8070 DISP
8080 RETURN 1
8084 IF N7=1 THEN 8090
8085 IF N7=2 THEN 8092
8088 LABEL (*,1.7,0.7,0,2/3)"O"
8089 GOTO 8100
```

```
8090 LABEL (*,1.7,0.7,0,2/3)"+"
8091 GOTO 8100
8092 LABEL (*,1.7,0.7,0,2/3)"X"
8100 DISP
8110 RETURN 1
8120 DISP "POINT OFF SCALE";
8130 RETURN 1
8500 DEF FNZ(X)
8510 Y=B[D1+1]
8520 FOR J=D1 TO 1 STEP -1
8530 Y=Y*X+B[J]
8540 NEXT J
8550 RETURN Y
9000 FOR I=1 TO 11
9010 B[I]=0
9020 NEXT I
9030 FOR I=1 TO 66
9040 C[I]=0
9050 NEXT I
9055 D2=2
9060 N=W=S1=S2=S3=S4=S5=0
9065 B[1]=1
9070 RETURN
9500 IF Q1=2 THEN 9630
9510 IF Q1=H[1]+1 THEN 9610
9520 E1=E2=E3=E4=0
9530 FOR E9=(Q1-1) TO (Q1+1)
9540 E1=E1+LGT(H[E9])
9550 E2=E2+(LGT(H[E9]))↑2
9555 E6=(382.3*G[E9]-K4)/382.3
9560 E3=E3+LGT(E6)
9570 E4=E4+LGT(H[E9])*LGT(E6)
9575 NEXT E9
9580 N2=(3*E4-E1*E3)/(3*E2-E1↑2)
9590 E5=N2
9600 RETURN
9610 N2=E5
9620 RETURN
9630 N2=(LGT((382.3*G[3]-K4)/382.3)-LGT((382.3*G[2]-K4)/382.3))
9640 N2=N2/(LGT(H[3])-LGT(H[2]))
9650 RETURN
9660 END
```

APPENDIX E

COMPLETE SET OF QUALITY CONTROL CURVES

Enclosed is a complete set of the curves generated during the program. These curves are grouped according to time after blending. For each time period, there are: five curves (one for each shear rate) which show the pressure drop (in divisions) versus concentration, the jet diameter versus concentration curve at a shear rate of 4409 sec^{-1} and the delta divisions versus concentration curve. Figures E-1 through E-3 are used 5 minutes after blending; E-4 through E-6 are for 9-minute old fuel and E-7 through E-9 are used for fuel which is 20 minutes old and older.



E-1. DIVISIONS VERSUS CONCENTRATION FOR FIVE SHEAR RATES. 5-MINUTE FUEL

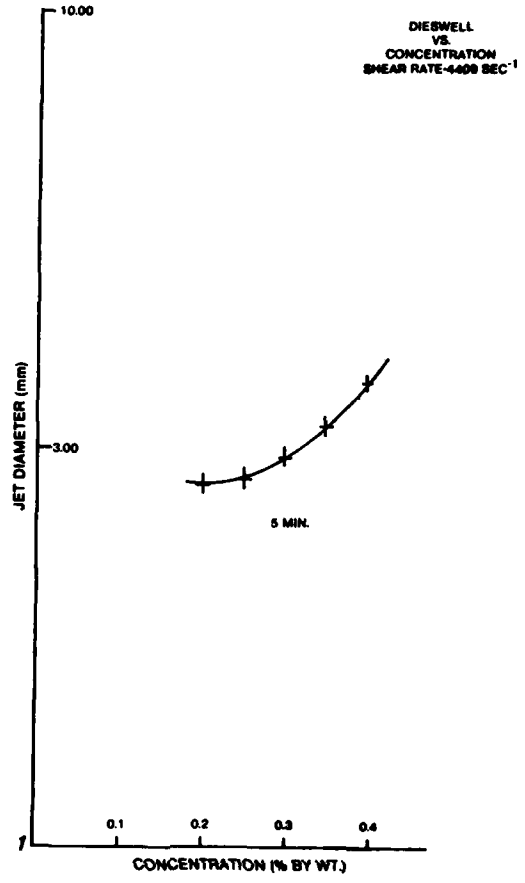


FIGURE E-2. JET DIAMETER VERSUS CONCENTRATION. FIVE-MINUTE OLD FUEL

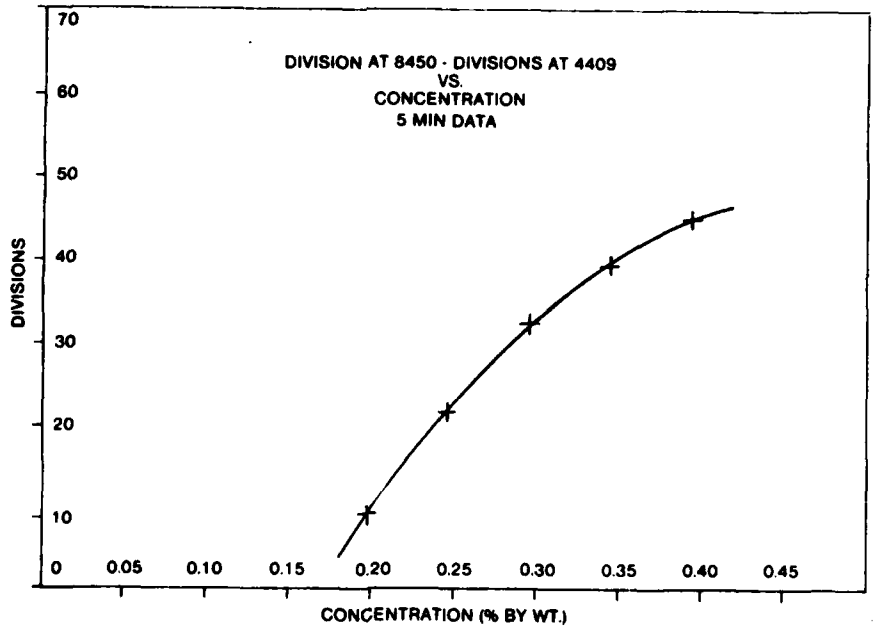


FIGURE E-3. DELTA DIVISIONS VERSUS CONCENTRATION. FIVE-MINUTE OLD FUEL

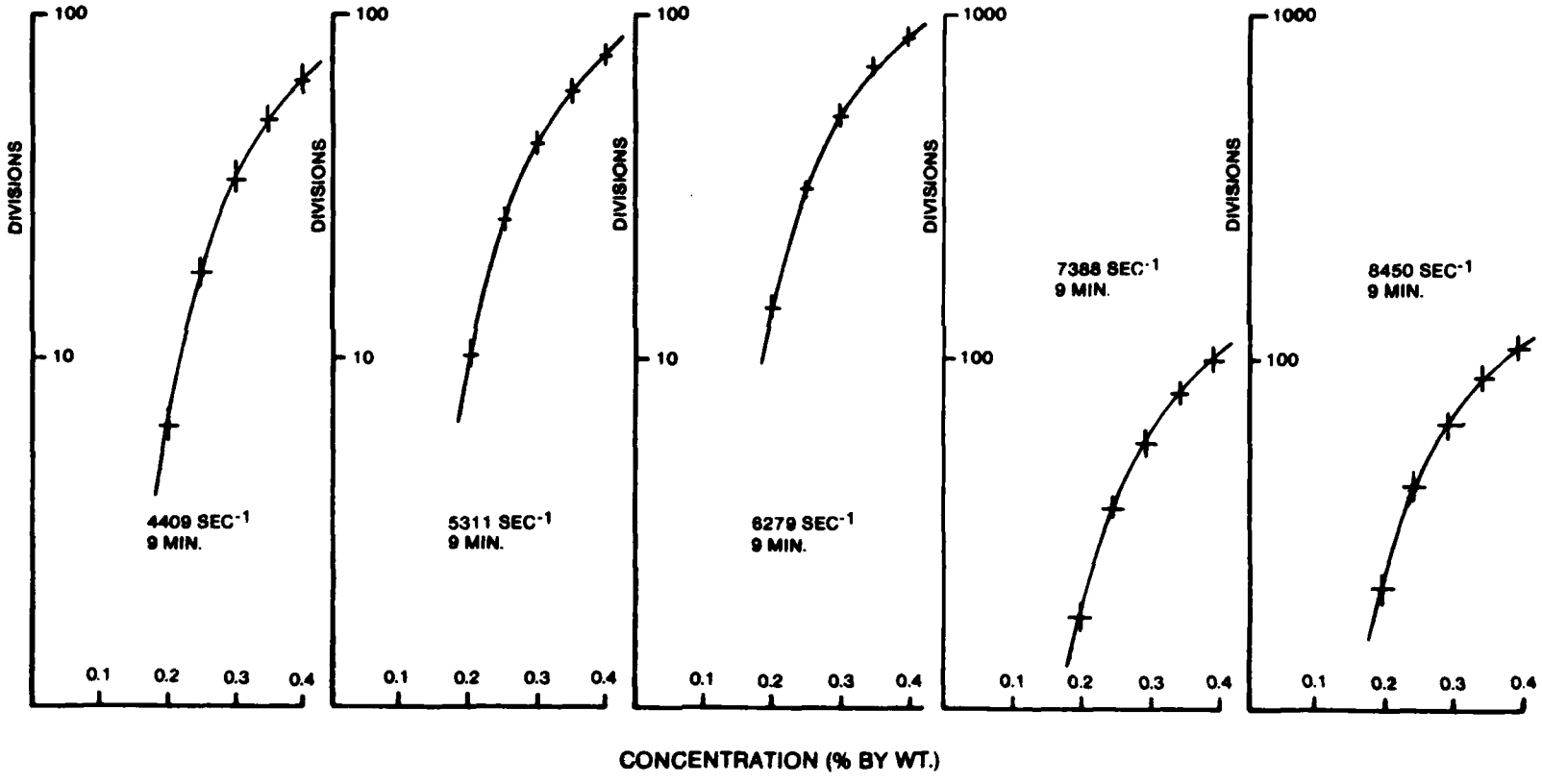


FIGURE E-4. DIVISIONS VERSUS CONCENTRATION FOR A NUMBER OF SHEAR RATES. NINE-MINUTE OLD FUEL

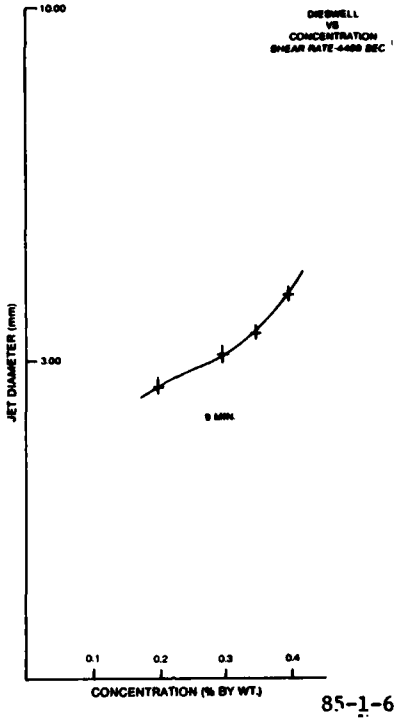


FIGURE E-5. JET DIAMETER VERSUS CONCENTRATION FOR NINE-MINUTE OLD FUEL

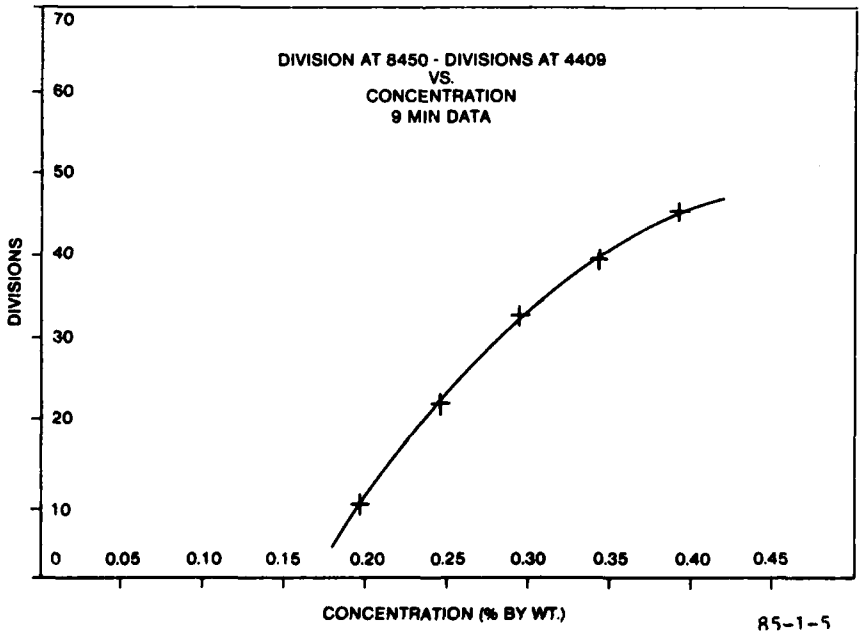


FIGURE E-6. DELTA DIVISIONS VERSUS CONCENTRATION FOR NINE-MINUTE OLD FUEL

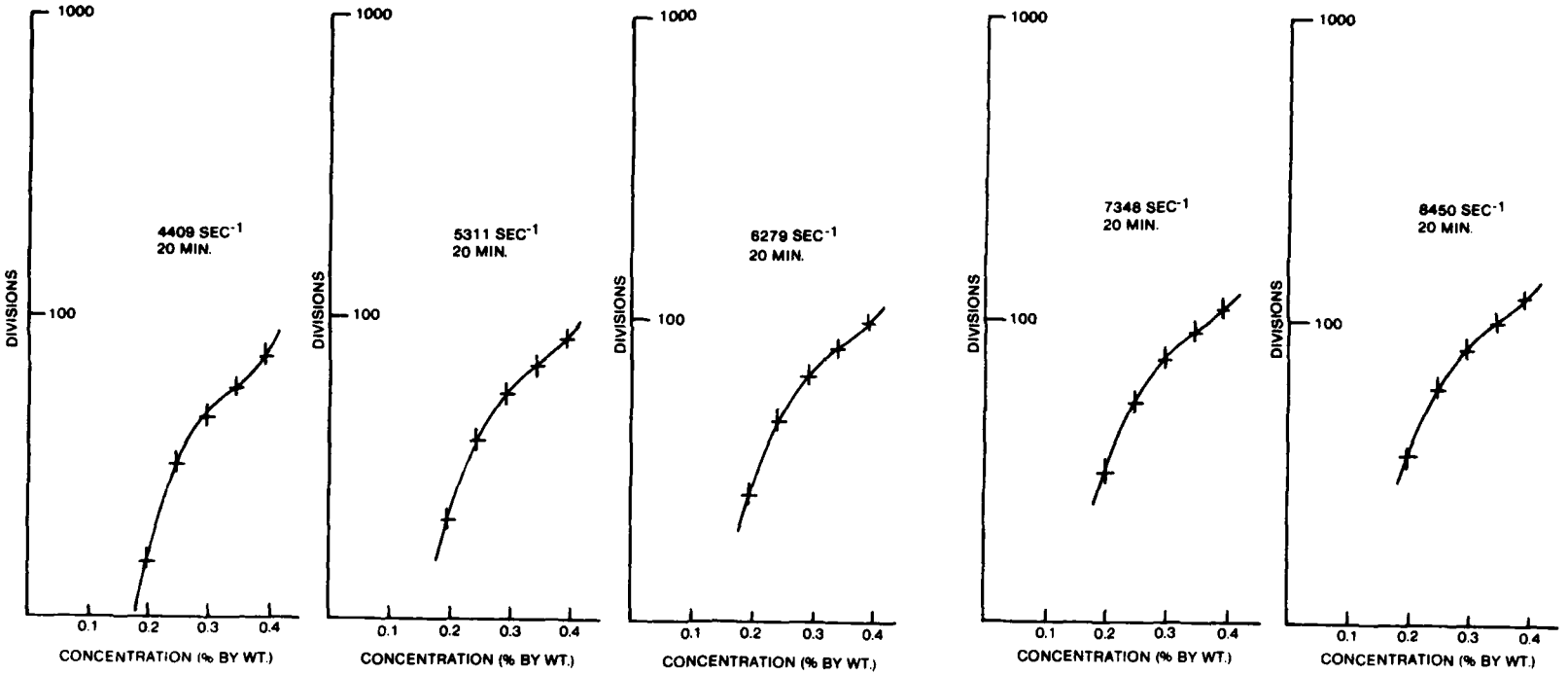


FIGURE E-7. DIVISIONS VERSUS CONCENTRATION FOR FIVE SHEAR RATES. TWENTY-MINUTE OLD FUEL

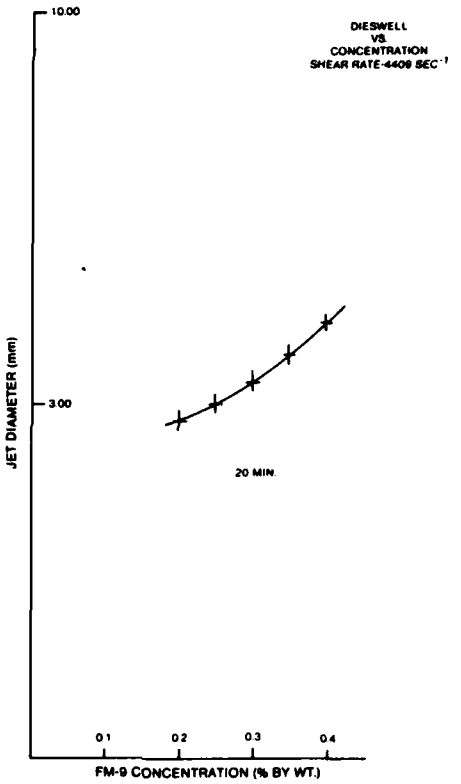


FIGURE E-8. JET DIAMETER VERSUS CONCENTRATION FOR 20-MINUTE OLD FUEL

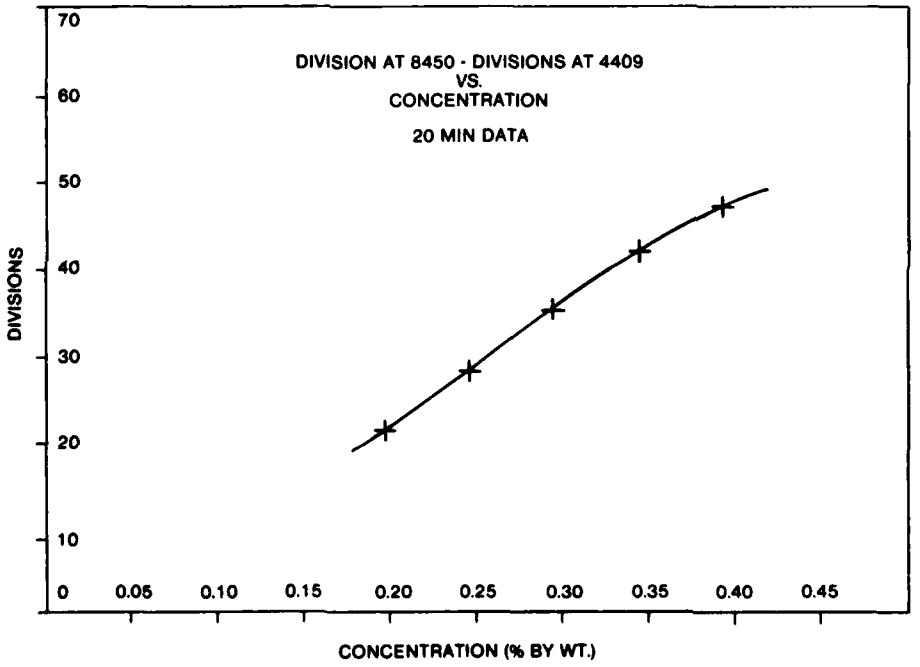


FIGURE E-9. DELTA DIVISIONS VERSUS CONCENTRATION FOR 20-MINUTE OLD FUEL

APPENDIX F

DESCRIPTION OF LABORATORY TEST CONDUCTED IN SUPPORT OF THE QUALITY CONTROL PROJECT

The filter ratio test was originally conceived by the Royal Aircraft Establisment and later modified by both the Jet Propulsion Laboratory and the Federal Aviation Administration (FAA) Technical Center. The unit used in this report utilized an electronic timer with optical sensors placed at the timing reference points in figure F-1. The filters used in this apparatus were precut disks of 16-18 micron twilled Dutch weave stainless steel cloth (164 x 1400 mesh with a wrap diameter of 0.07 millimeter (mm) and a weft diameter of 0.04 mm) approximately 45 mm in diameter. The antimisting kerosene (AMK) samples were tested at 20° C ± 1° C, 30 minutes after blending, utilizing the following procedure:

1. Make sure the filter apparatus has been rinsed clean with Jet A and then drained. Residual AMK can influence the filter time of the next sample.

2. Place an unused filter on the lower filter plate, positioning it in the center so that it overlaps the edge of the orifice.

3. Both '0' rings should be properly seated. Align the upper assembly and the lower filter plate the same way each time. Attach the lower filter plate to the upper assembly and secure the screws, tightening them to the same tolerance each time.

4. Insert a rubber stopper in the bottom orifice, choosing a size which does not contact the filter. Hold the stopper steady until removal. Excess motion may induce gelation in the filter.

5. Tilt the apparatus slightly and pour the reference Jet A slowly down the side of the tube. (The reference Jet A is from the same lot as the base fuel used to blend the sample.)

6. Once the tube is about 3/4 filled, return it to vertical, add fuel till it overflows into the gallery. Set the timer.

7. Remove the rubber stopper. Record the time between the timing reference points.

8. When the apparatus has drained, replace the stopper and tilt the apparatus slightly. Pour the sample of AMK slowly (90 seconds) down the side of the tube not letting it hit bottom directly.

9. Repeat steps 6 and 7.

10. Remove the filter and clean the apparatus with Inhibisol.

The filter ratio is reported as the AMK time divided by the Jet A time.

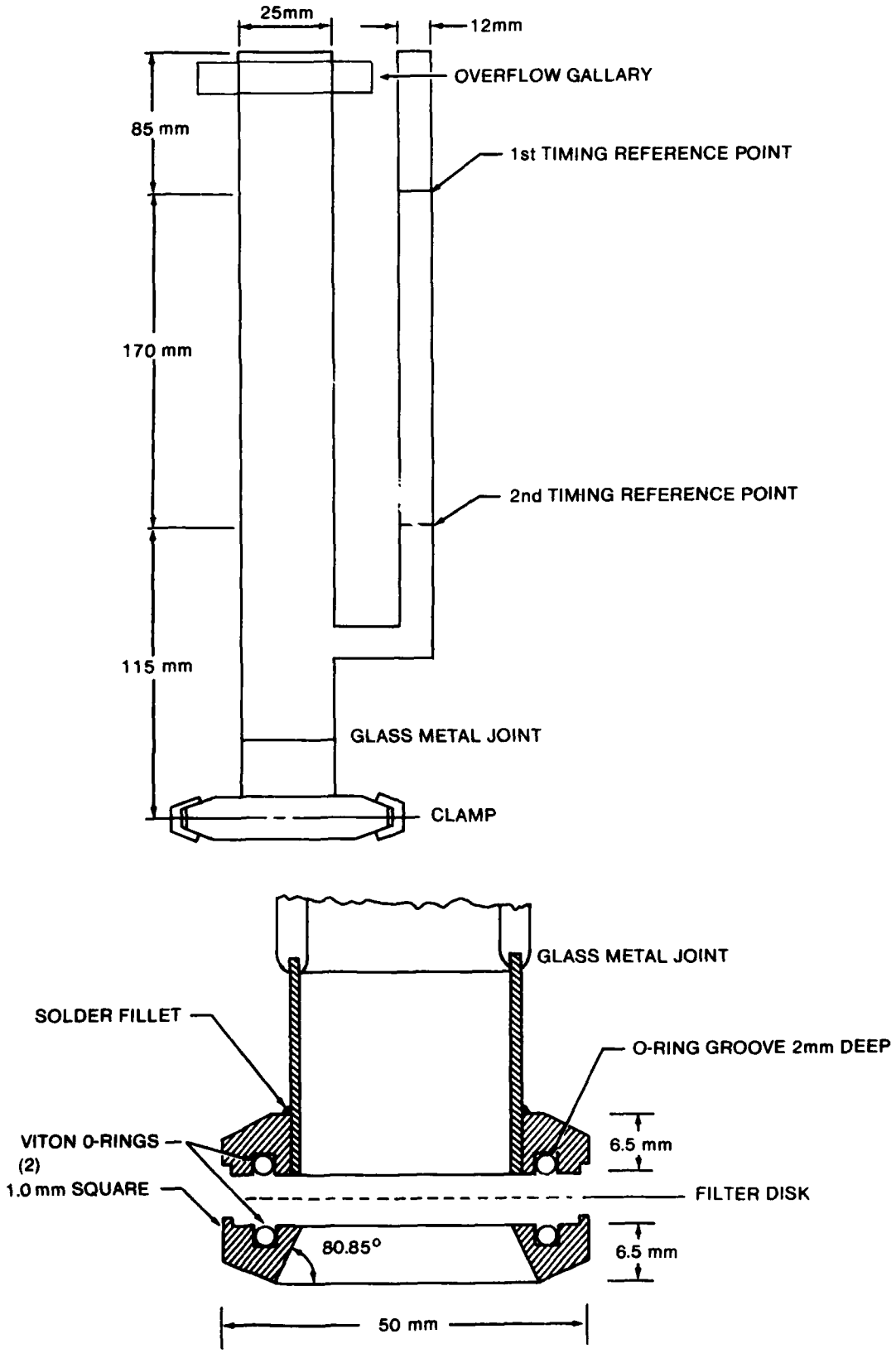


FIGURE F-1. DESCRIPTION OF FILTER RATIO APPARATUS

The orifice cup was originally developed by the Imperial Chemical Industries. The cup dimension are shown in figure F-2.

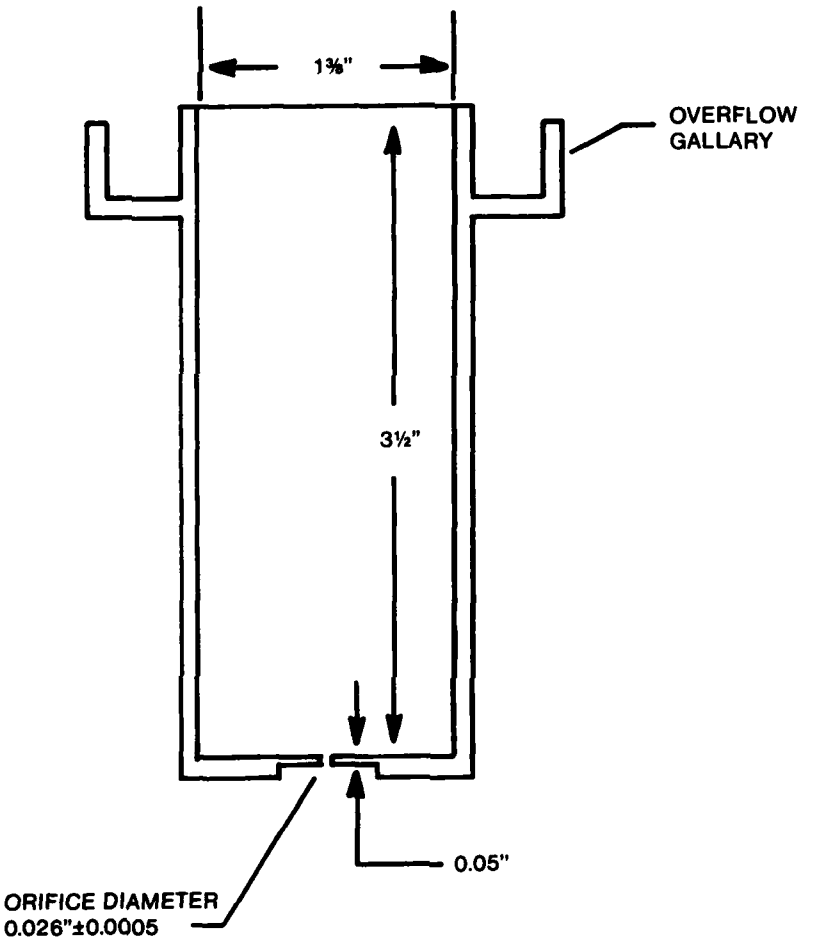


FIGURE F-2. CROSS SECTION OF CUP TEST APPARATUS

The cup operating procedure is as follows:

1. Suspend the cup apparatus inside a ring on a ring stand; allow enough room below the cup to permit introduction of a graduated cylinder (preferably 10 cc).

2. Place a finger over the hole, tilt the cup slightly to one side. Pour in a fuel sample allowing fuel to run down the sides of the cup rather than hitting the bottom directly.

3. Let fuel overflow into the gallery.

4. Once the cup is full, allow 30 seconds before releasing finger.

5. Release finger at 30-second mark, recovering the fuel in a beaker beneath the orifice. Let the cup drain for another 30 seconds.

6. At the 1-minute mark (i.e., 30 seconds after releasing finger), simultaneously slide the graduated cylinder in place of the beaker and collect the fuel being discharged through the orifice for 30 seconds. Remove the graduated cylinder and replace with the beaker.

7. Record the amount collected in the graduated cylinder.

8. Discard collected material and clean the apparatus with Inhibisol. Make certain the orifice is not blocked with lint or other fine debris.

9. After cleaning, tne cup is stored in Jet A.

The cup values are reported as milli-liter per 30 seconds.

The nephelometer tests were conducted in accordance with the EPA's Standard Methods for Examining Water and Wastewater, Water Test 214, Turbidity, on a unit manufactured by Monitek. The solids test was conducted in accordance with ASTM-D381 with the following additions: each 50 mℓ sample was weighed and the results reported on a percent weight/weight basis.

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